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VOLUME I

(2)

CONTROL-DISPLAY INTEGRATION PROGRAM

HIGH ACCELERATION COCKPIT CONTROLLER LOCATIONS

Volume I - Program Summary

McDonnell Aircraft Company
St. Louis, Missouri 63166

May 1975

TECHNICAL REPORT AFFDL-TR-75-58, VOLUME I

Final Report for period June 1974 - December 1974

AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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This final report was submitted by McDonnell Aircraft Company, St. Louis, Missouri, a division of McDonnell Douglas Corporation, under Contract F33615-74-C-3093, job order 61900326, with the Air Force Flight Dynamics Laboratory. Mr. James A. Uphaus, Jr. was the Laboratory's Technical Monitor.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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A controller-throttle design integration program was conducted for an advanced fighter concept with direct lift, direct side force, and high acceleration maneuvering capabilities. Several controller-throttle configuration design alternatives were evaluated in a high acceleration cockpit mock-up by USAF pilots in a static simulation evaluation phase. Cockpit and controller functional capabilities were tailored to satisfy operational needs for normal flight and combat phases and were evaluated within the context of a fighter

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20. ABSTRACT

mission. Objective and subjective data including reach and vision envelopes, task performance times, and pilot preferences from paired comparison and interview questionnaires were utilized to rank the configurations evaluated. Several principal areas for future high acceleration cockpit development were defined.

FOREWORD

This technical report summarizes research performed at McDonnell Aircraft Company (MCAIR), P.O. Box 516, St. Louis, Missouri, 63166, a division of McDonnell Douglas Corporation, under Air Force Contract F33615-74-C-3093, Project 6190 0326, from 1 June 1974 to 1 December 1974. This report consists of three volumes:

Volume I	Program Summary
Volume II	Test Plan
Volume III	Onsite Pilot Evaluations

The contract was initiated under AF Project 6190, "Control-Display for Air Force Aircraft and Aerospace Vehicles," which is managed by Mr. J. H. Kearns, III, as project engineer and principal scientist for the Flight Deck Development Branch (AFFDL/FGR), Flight Control Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The work was performed as a part of Task Number 6190 0326 under the guidance of Mr. J. A. Uphaus, Jr. (AFFDL/FGR) as task engineer.

High Acceleration Cockpit Program activities are conducted within the McDonnell Aircraft Company (MCAIR) Advanced Aircraft Systems Project. This project is directed by Mr. H. H. Ostroff, Director - Advanced USAF Fighter/Attack Systems, and is an element of MCAIR Advanced Engineering, directed by Mr. H. D. Altis, Director - Advanced Engineering Division. The High Acceleration Cockpit Project is managed by Mr. J. M. Sinnett, Project Advanced Design Engineer.

The principal contributors to this volume in addition to the authors, and for the program elements reported here, are: D. C. Gendreau, Senior Design Engineer; S. L. Loy, Senior Engineer Psychologist; L. L. Pingel, Senior Design Engineer; and J. Roberts, Jr., Technical Specialist, Avionics.

Successful accomplishment of the cockpit engineering design/integration and configuration evaluation tasks was made possible through the patient cooperation and helpful suggestions of the Air Force Pilot Team: Maj. Jim Roberts, Capt. Bert Strock, Capt. Tom McKnight, and Capt. Tim Mikita.

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LIST OF ABBREVIATIONS AND SYMBOLS

AAA	Anti-Aircraft Artillery
A/A	Air-to-Air
AAI	Air-to-Air IFF
A/B	Afterburner
ACM	Air Combat Maneuvering
ADI	Attitude Director Indicator
AFCS	Automatic Flight Control System
A/G	Air-to-Ground
AI	Airborne Interceptor
ANOVA	Analysis of Variance
AP	Avionics Panel
ATT	Attitude
Auto	Automatic
BIT	Built In Test
C	Configuration(s)
Chan	Channel
Cmps	Compass
CMR	Camera
Comm	Communications
Config	Configuration
CONT	Contrast
D	Desirable
DFC	Direct Force Control
Depr	Depression
Displ	Display

LIST OF ABBREVIATIONS AND SYMBOLS (CONTD)

DLF	Direct Lift
DSF	Direct Side Force
ECM	Electronic Countermeasures
ECS	Environmental Control System
Eject	Ejection
Eng	Engine
Elev	Elevation
EO	Electro Optical
F	Statistical Distribution
FBW	Fly-By-Wire
Flt Cont	Flight Controller
Freq	Frequency
ft	Feet
Fus	Fuselage
G	Load Factor
Gen	Generator
HAC	High Acceleration Cockpit
HSI	Horizontal Situation Indicator
HUD	Head-Up Display
Hyd	Hydraulic
I/F	In-Flight
IFF	Identification Friend or Foe
IFR	In Flight Refuel
ILS	Instrument Landing System
in.	Inches

LIST OF ABBREVIATIONS AND SYMBOLS (CONTD)

INS	Inertial Navigation System
INST	Instrument(s)
KEAS	Knots Equivalent Airspeed
L	Left Hand
lb, LB	Pound, Pounds
LGB	Laser Guided Bomb
LO_2	Liquid Oxygen
IP	Identification Point
M	Sample Mean
max	Maximum
MCAIR	McDonnell Aircraft Company
MDC	McDonnell Douglas Corporation
MIL-STD	Military Standard
MIP	Main Instrument Panel
MSD	Multi-Sensor Display
MVR	Maneuvering
NAV	Navigation
NS	Not Significant
O	Objective
O_2	Oxygen
P	Pilot(s)
P/B	Push Button
P/C	Power Control Hydraulic System
Pos	Position
Pres	Pressure

LIST OF ABBREVIATIONS AND SYMBOLS (CONTD)

R	Right Hand, Required
R and D	Research and Development
Ref	Reference
RDR	Radar
Rds	Rounds
RPM	Revolutions per Minute
RWR	Radar
S	Subjective, Standard Deviation
SAM	Surface-to-Air Missile
SEA	South East Asia
SRM	Short Range Missile
T	Task(s)
TACAN, TCN	Tactical Air Navigation
TDS	Target Designator Set
TEWS	Tactical Electrical ·ırfare System
Tgt	Target
THR	Throttle
UHF	Ultra High Frequency
USAF	United States Air Force
UTL	Utility Hydraulic System
VC	Pilot Visual Cockpit Sensory Mode
VEC	Vector
VEL	Velocity
VI	Visual Identification
V/V	Vertical Velocity
W	Kendall's Coefficient of Concurrence

SECTION I

INTRODUCTION AND SUMMARY

We are entering an era where fighter aircraft maneuvering design and performance capabilities may exceed those of the pilot unless additional measures for load factor protection are implemented. Even the simplest of fighter designs, typified by the maneuvering performance illustrated in Figure 1, can exceed recognized limitations of pilots equipped with only a conventional G suit (3G region) throughout more than 20% of the fighter's flight envelope. This translates to more than 75% of the Projected Air Combat Zone.

The use of a reclining seat in the High Acceleration Cockpit has the potential for substantially improving the pilot's ability to make full use of the maneuver performance inherent in advanced fighters. Use of the reclined body position greatly minimizes detrimental physiological effects during air combat maneuvers, References (1) and (2). In addition to providing the pilot with load factor protection for short periods during the initial maneuvering phases of air combat engagements (transient attack and evasive maneuvers), the reclined seat also has potential for improving pilot performance at moderate G levels by removing the need for vigorous straining exercises to maintain perceptual and cognitive functions.

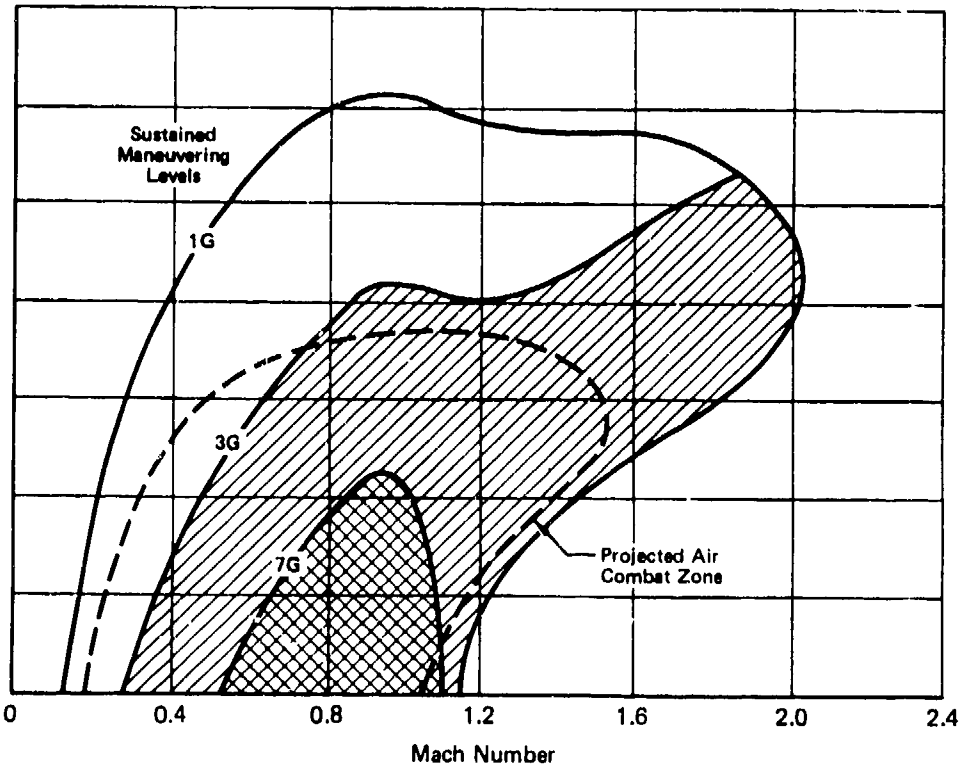

FIGURE 1
AIR COMBAT MANEUVERING

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During the weapons release phases, air combat simulation studies have shown that load factor levels are generally in the range of 3 to 5G. Here the HAC will provide the pilot with that physiological edge necessary for improved tracking and higher kill ratios.

The basic element of the high acceleration cockpit is a seat which articulates to a reclined position, thus reorienting the pilot with respect to the airplane resultant load factor vector. Acceleration is applied transverse to the pilot axis resulting in a significant reduction in height of the hydrostatic column between the heart and carotid artery, and to the lower extremities. As a result, eye level blood arterial pressure can be maintained, and venous pooling reduced; also heart rate is lowered, Reference (2). The relaxed G tolerance (uninflated G suit and no straining) increases with increasing seat back angle as shown in Figure 2 (Reference (2)). Peak heart rate also decreases as a function of higher back angles.

Some minor degree of G protection, achieved through reclining, may be sacrificed by supporting the head to provide forward vision. A head rest return angle of approximately 40° elevates the head slightly; negating, to a minor degree, the load vector/arterial axis advantage gained by reclining. Use of the head rest as noted enables the pilot to view all primary displays and tracking aids under G so that he can effectively use standard cockpit displays with his newly acquired tolerances.

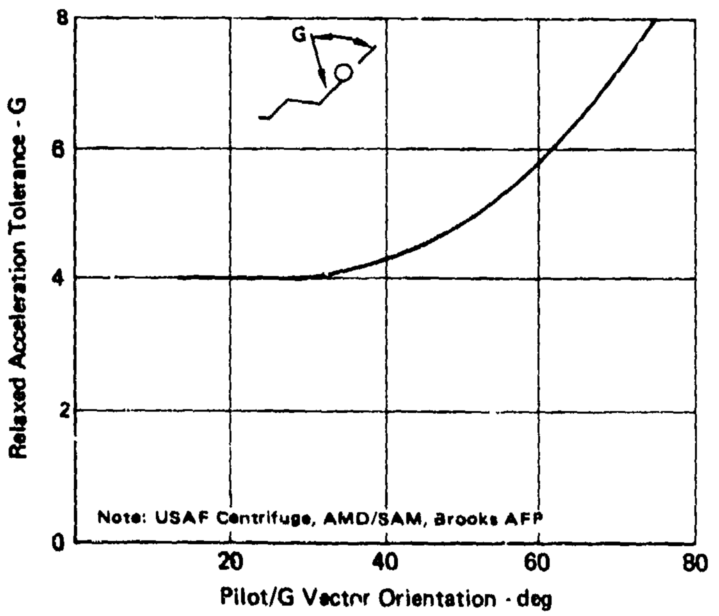

FIGURE 2
RELAXED G TOLERANCE

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Mechanization of the high acceleration concept within an aircraft is illustrated in Figure 3, for a seat articulating between 30° and 65°. With this concept, the ejection seat and launch rails are installed in a normal upright position, (15°-30°, depending upon initial design). Upon pilot command, the seat is driven to a lifting/reclined position for maneuvering load factor protection. In this position, pilot external vision envelopes are retained along with necessary internal cockpit vision and reach, Reference (3). Upon completion of the hard maneuvering phases, the pilot may select a return to "upright" or other intermediate positions of comfort for the remainder of his mission.

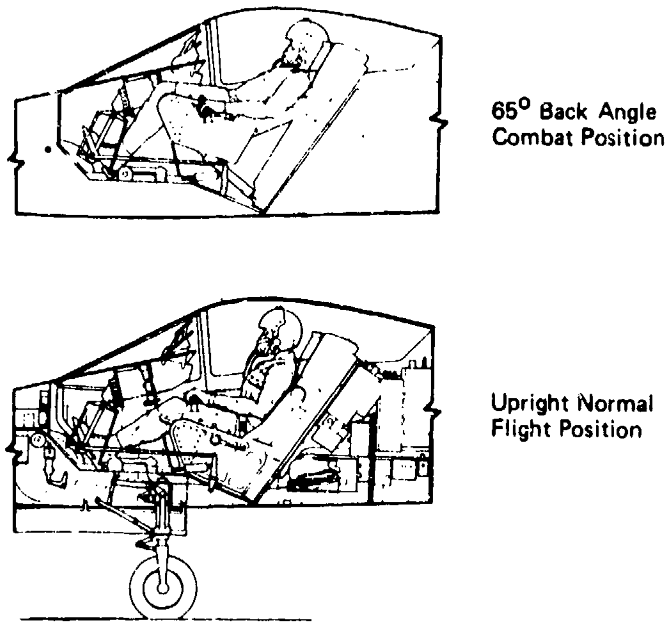

FIGURE 3
HIGH ACCELERATION COCKPIT

In a previous cockpit design/integration program, Reference (4), the primary objective was to provide a usable and effective advanced fighter cockpit design which accommodated an articulating seat. During the referenced effort, it became evident that a major factor influencing both the design and utility of the cockpit and articulating ejection seat was the location and mechanization of the flight and throttle controllers. Two controller locations evaluated in the previous program were: 1) a Fixed Console Mounted Configuration, and 2) an Over-the-Lap Seat Mounted Configuration. Controller access and pilot orientation proved to be a problem area for the console mounted location. The seat mounted design was preferred by the pilots due to excellent access and orientation in both the upright and reclined seat positions. However, from a design/integration viewpoint, the seat mounted over-the-lap controllers presented potential problems in the areas of ejection sequencing, in ejection seat design, and aerodynamic balance, in order to accommodate the controller/arm rest mechanization. These factors precipitated the Controller Locations Study reported herein.

PROGRAM OBJECTIVES

The primary objective of this program was to provide usable and effective controller location options for both the upright and reclined positions with minimum impact on crew station and ejection seat design. Specific tasks which permitted an orderly step-by-step development of useful controller location concepts were:

- Identify requirements in terms of geometric constraints, controller transducer volumes, and arm support
- Perform controller location screening studies to enable selection of two new concepts for pilot evaluation
- Determine the impact of the selected concepts on the control/display layouts
- Evaluate the selected configurations and the previously developed configurations using Air Force pilots to determine usability and acceptance
- Identify key design/development goals requiring productive effort prior to effective cockpit demonstration

PROGRAM APPROACH

The program approach was basically identical to that employed in the "High Acceleration Cockpits for Advanced Fighter Aircraft" program, Reference (4). The current program was additionally structured to allow operational pilot evaluation of alternative flight and throttle controller configurations. A classical design approach was employed. Major elements consisted of: (1) definition of pilot needs to accomplish individual tasks encountered in a typical fighter sweep mission; (2) provide the display/command capability within the cockpit to satisfy those needs -- directed toward specific requirements accompanying a given seat position, mission phase, and G level; (3) evaluation of controller design alternatives -- in a simulated task environment to provide a measure of overall acceptance of the high acceleration cockpit approach and a ranking of flight and throttle controller location alternatives; and (4) determination of concept acceptance by a large group of operational flighter pilots at Nellis AFB and Edwards AFB.

RESULTS

The use of a full scale engineering design aid facilitated resolution of the major design and integration aspects and permitted rapid evaluation of alternative controller location concepts. The quick change features of the design aid also enabled its use in a test and evaluation phase to illustrate the features of the four controller locations and to evaluate advantages and disadvantages of each concept. Four operational Air Force pilots participated in the formal evaluation phase providing a first order operational critique. As a result of the testing, concepts were ranked in order of pilot utility and preference.

Formal evaluation concentrated on four controller integration concepts. Two baseline concepts were retained from the Reference (4) study: (1) Fixed Console Mounted Controllers; and (2) Over-the-Lap Seat Mounted Controllers. The two new configurations, developed in this effort, are Instrument Panel Mounted Controllers and Console Mounted Controllers, which raise and lower in sequence with the reclining seat. The shoulder pivot seat selected during the referenced study, was used for this evaluation. Testing included a combination of objective measures (vision/reach envelopes, eye/head motion, and task performance times) and subjective measures (mission evaluation of cockpit/controller use, paired comparison questionnaires on equipment and mission phase importance, pilot interviews and debriefings).

Compilation of objective and subjective test data indicates a preference for the Console Mounted Controllers. As implemented here the controllers have two degrees of freedom: (1) they adjust to pilot comfort in the longitudinal plane; and (2) they raise and lower in the vertical plane, consonant with seat articulation. The selected concept is shown in Figure 4. Preferences are illustrated by the "box score" summary presented in Table 1. The seat mounted concept was the second choice. The pilots' opinions on controller location preference were consistent for the paired comparison questionnaires and pilot interviews.

The work reported here forms the basis for recommending additional high acceleration cockpit research and development. Aggressive research and development activity should be implemented for: development of an articulating ejection seat, definition of reclined limb and head support/mobility needs under G, definition of aircraft induced vibrations effects, and implementation of a near term flight demonstration system. As in the referenced study, definition of a minimum cockpit size also highlights the importance of parallel R&D for reduction in bulk and improved comfort and efficiency of pilot personal equipment and combat survival gear universal to all controller concepts.

Remaining sections of this volume summarize the controller location design approach, discuss evaluation of alternative controller concepts and results of the evaluation, and present the principal program and technical issues surrounding high acceleration cockpit development.

The Test Plan utilized in this evaluation is presented in Volume II of this report. The Onsite Pilot Evaluation results are presented in Volume III of this report.

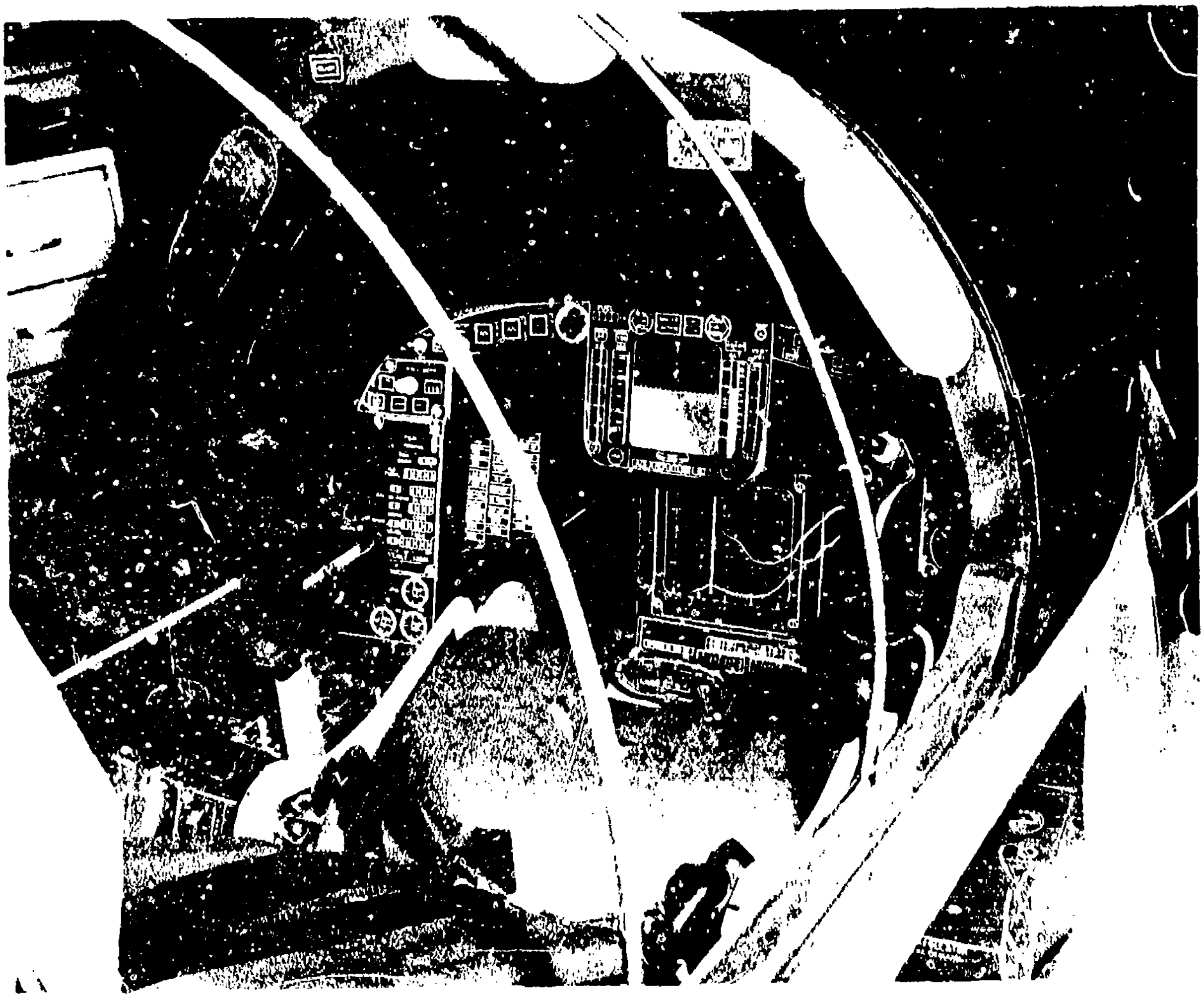

FIGURE 4
SELECTED CONTROLLER CONFIGURATION

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TABLE 1
CONFIGURATION RANKING

SESSION		CONFIGURATION A	CONFIGURATION B	CONFIGURATION D	CONFIGURATION E
OBJECTIVE					
Physical Reach and Interference Envelope		1	2	4	4
Visual Interference Envelope		4	1	2	3
Task Performance Measures (1)	20°	2	4	1	3
	65°	4	1	3	2
Eye/Head (1) Movement — Vertical	20°	3	4	2	1
	65°	4	3	1	2
Eye/Head (1) Movement — Horizontal		4	2	1	3
SUBJECTIVE					
Pilot Task Performance Based on Mission Scenario Evaluation		1	4	2	3
Cockpit/Controller Configuration Preference Based on Paired Comparisons		1	3	2	4
Pilot Interview Questionnaire		1	3	2	4
Average		2	3	1	4

Notes: Most Favored Configuration - 4
Least Favored Configuration - 1

Configuration A - Fixed Console Mounted Controllers
Configuration B - Over-the-Lap Seat Mounted Controllers
Configuration D - Instrument Panel Mounted Controllers - Vertical Adjust
Configuration E - Console Mounted Controllers - Vertical Travel

(1) These data are presented as an order ranking only. Statistically significant differences at either the 0.01 or the 0.05 level were not universally obtained across the different configurations.

SECTION II

DESIGN BASIS

Crew station design represents a combination of human engineering plus mission/functional capabilities and weapon system design goals. The purpose of this study was to address the integration of the flight and throttle controls in an existing engineering design aid, which is representative of an advanced minimum size air superiority fighter. The flight and throttle controllers are the primary pilot/weapon system interface. Utility and effectiveness for all selected locations is imperative. Consideration of an articulating seat imposes an additional requirement in that the utility of the controllers must also be effective for all seat positions.

AIRCRAFT CONSIDERATIONS

The design aid, shown in Figure 4, is representative of the crew station for an advanced, lightweight, highly maneuverable fighter concept. The rationale employed in arriving at the aircraft geometry (of which the design aid is representative) is presented in Reference (4). For this study, the primary features of the aircraft configuration which impact the location and mechanization of the flight and throttle controls are sill location and seat width. The distance between the sills in the area of the controller is 26 inches. This width, in conjunction with a seat bucket width of 18 inches, controls the allowable flight and throttle grip and mechanization envelopes for all controller concepts located between the seat and sill. A cross section of the design aid at a typical controller location is shown in Figure 5. This figure illustrates the allowable envelope for aircraft mounted controller concepts.

The vertical distance between the seat reference point, side consoles, and the lower surface of the sills also influences the utility of a controller location concept. For fixed locations, variations in sill height can materially alter both the clearances and location of the grip. The sill height influences the design and mechanization for concepts which raise and lower in harmony with the articulating seat.

Other aircraft geometric factors which influenced the design of the controllers and the mechanization concepts include: internal moldlines, console width, and location of primary aircraft structural members.

FUNCTIONAL REQUIREMENTS

In addition to the aircraft geometric considerations, the integration of a high acceleration crew station requires that the primary and secondary controls and displays be situated to ensure pilot effectiveness. Primary consideration was given to pilot tasking for each mission phase and each seat position. The pilot task analysis specified those information requirements necessary for achieving the mission objectives in mission phases compatible with both normal and reclined seat positions.

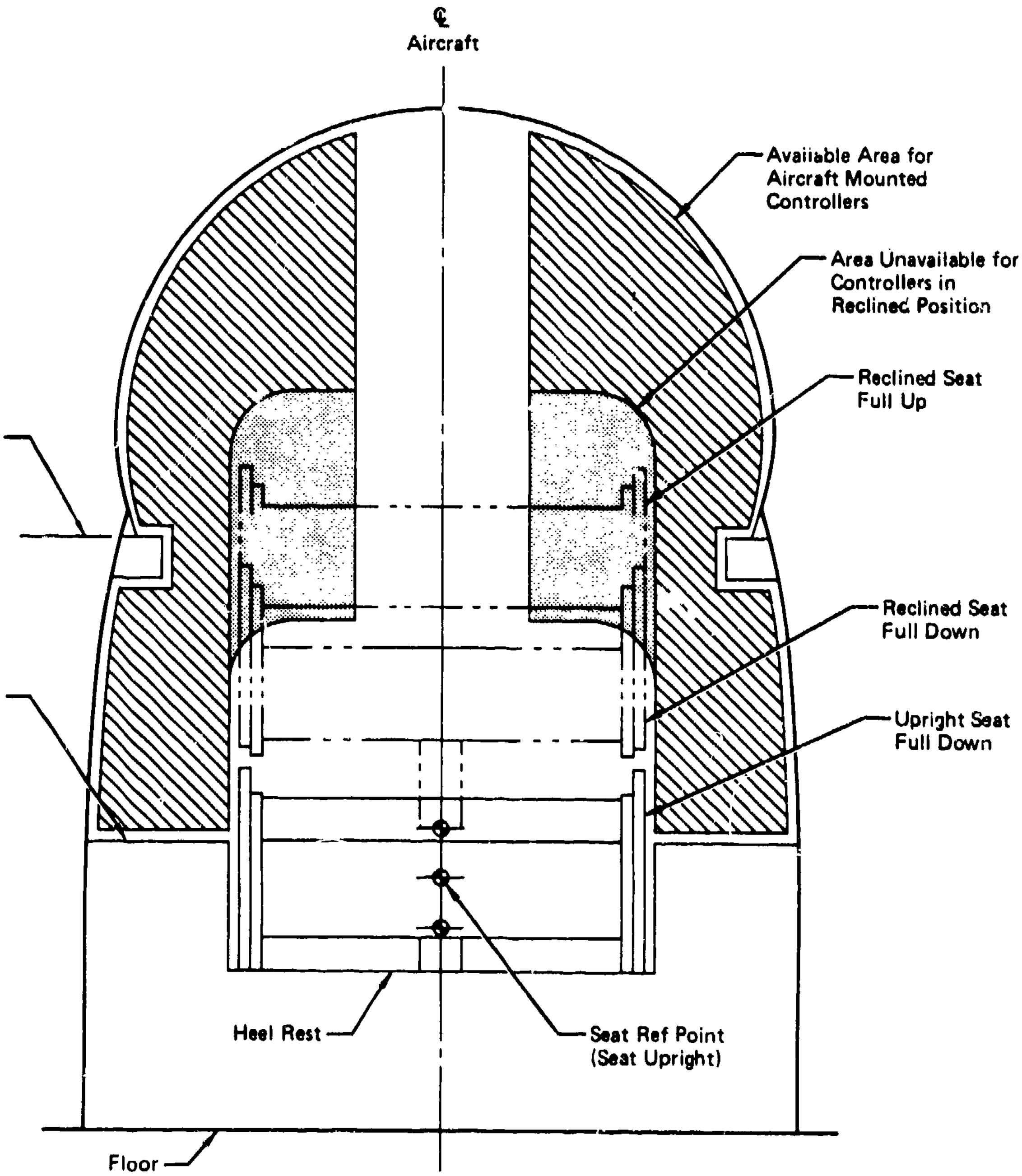

FIGURE 5
CONTROLLER LOCATION ENVELOPE

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The primary controls and display philosophy was to provide optimum head-up operation during close-in combat. This head-up capability was enhanced by the following significant features:

- o Attack mode and weapon are selected by a control on throttle
- o Attack displays for the selected weapon are automatically provided on the Head-Up-Display (HUD)
- o While tracking the target on HUD, the pilot can command radar designation and elevation and missile seeker acquisition by depressing switches on the flight control stick and throttles.

The number and frequency of pilot tasks during the attack phases realized through earlier task load analysis in Reference (5), led to this design approach. This was found to be an excellent solution to provide full pilot capability while avoiding task overlap.

In the noncombat mode, the cockpit design approach was to reduce the number of pilot tasks for normal flying operations. Pilot workload is eased by the following features considered included in the airframe subsystems:

- o Automatic fuel transfer and tank sequencing to eliminate switching and selective feed if required to maintain a balance state
- o Multiple fuel quantity indications, fuel level low, and Bingo fuel warning
- o Rapid engine ignition for ground and air starting
- o Environmental control system with automatic temperature control and continuous windshield anti-fogging
- o Balanced cockpit lighting with control flexibility
- o Master Caution Light and TEWS warning lights located at the center of the primary field-of-view
- o Built-in-test monitoring.

A sample listing of pilot tasks for the outbound cruise is presented in Table 2. Codes are also listed here for the types of equipment required and test measure. By evaluating the pilot tasks for each mission phase in conjunction with pilot workload, priorities for selecting and locating the controls and displays were established. The pilot workload summary presented in Table 3 summarizes task element requirements for each mission phase including two classes of emergency: (1) ejection; and, (2) seat stuck in the reclined position. Each task was categorized as either subjective (visual) or objective (requires physical action) for subsequent test evaluation.

TABLE 2
SAMPLE PILOT WORKLOAD

1	CRUISE (CHECKOUT AND INS UPDATED)	IP	0	S
2	ENGAGE AFCS PILOT RELIEF MODES	VCL	33	O
3	CHECK FBW CAUTION	VC	33	S
4	MONITOR ROLL (+-60 DEG)	VC	49	S
5	MONITOR PITCH (+-45 DEG)	VC	49	S
6	ACTIVATE FBW ATT HOLD	VCL	33	O
7	POSITION FLIGHT CONTROLLER (1 LB FORCE)	R	83	S
8	SENSE ATTITUDE HOLD DISENGAGE	IP	0	S
9	RELEASE MANUAL PRESSURE ON CONTROLLER	R	83	S
10	ACTIVATE FBW VEL VEC HOLD	VCL	33	O
11	POSITION CONTROLLER (3.5 LBS LONGITUDINAL)	R	83	S
12	MONITOR ALTITUDE	VC	52	S
13	RELEASE MANUAL PRESSURE ON CONTROLLER	R	83	S
14	MONITOR FBW STATUS	VC	33	S
15	MONITOR KIAS (AS REQUIRED)	VC	51	S
16	MONITOR MASTER CAUTION (AS REQUIRED)	VC	43	S
17	MONITOR ALTITUDE (AS REQUIRED)	VC	52	S
18	MONITOR HEADING AND RANGE (AS REQUIRED)	VC	53	S
19	MONITOR ATTITUDE (AS REQUIRED)	VC	49	S
20	MONITOR FLY-TO-POINT (AS REQUIRED)	VC	53	S
21	MONITOR THREAT DISPLAY (AS REQUIRED)	VC	53	S
22	MONITOR VERTICAL VELOCITY INDICATION (ASR)	VC	48	S
23	DISENGAGE AUTOPILOT (AS REQUIRED)	R	83	O
24	DISENGAGE FBW VEL VEC HOLD	VCL	33	O
25	CONTROL NEW ALTITUDE (AS REQUIRED)	VCR	83	S
26	ENGAGE FBW VEL VEC (AS REQUIRED)	VCL	33	O
27	DISENGAGE FBW ATTITUDE (AS REQUIRED)	VCL	33	O
28	CONTROL NEW ATTITUDE (AS REQUIRED)	VCR	83	S
29	ENGAGE FBW ATTITUDE (AS REQUIRED)	VCL	33	O
30	OPERATE INS	IP	57	S
31	DEPRESS (STEER) FIRST PLANNED CHECKPOINT	VCR	57	O
32	SELECT STEERING MODE (NAV)	VCR	57	O
33	ACTIVATE MASTER MODE (ADI)	VCR	49	O
34	OBSERVE ADI FORMAT WITH BANK STEERING BAR	VC	49	S
35	OBSERVE POINTER AT DESTINATION BEARING	VC	53	S
36	OBSERVE MILES DISTANCE	VC	53	S
37	OBSERVE HEADING MARKER ON DESTINATION	VC	53	S

EVALUATION

EQUIP. USED

PILOT SENSORY MODE

IP - INFORMATION PROCESSING
VC - VISUAL COCKPIT
R - RIGHT HAND
L - LEFT HAND
S - SUBJECT TASK
O - OBJECTIVE TASK

TABLE 3
PILOT WORK LOAD SUMMARY

MISSION ELEMENTS	PILOT TASKS REQUIRED	QUANTITY OF EQUIP USED	TEST EVALUATION BALANCE			
			SUBJECTIVE		OBJECTIVE	
			No.	%	No.	%
1. Preflight	469	65	200	42.6	269	57.4
2. Instrument Takeoff	94	34	65	69.1	29	30.9
3. Cruise	185	34	87	47.0	98	53.0
4. SAM Evasion	35	15	13	37.1	22	62.9
5. LGB Strike	97	29	53	54.6	44	45.4
6. Strafing Attack	55	28	17	30.9	38	69.1
7. Air-to-Air Combat	67	34	31	46.3	36	53.7
8. Inflight Refueling	76	20	20	26.3	56	73.7
9. Approach/Landing	158	27	80	50.6	78	49.4
10. Post Flight	38	21	11	28.9	27	71.1
11. Emergency						
A. Ejection	26	7	8	30.8	18	69.2
B. Seat in Recl Pos	8	3	3	37.5	5	62.5
TOTALS	1308	94	588	45.0	720	55.0

The pilot tasks and workload are presented in greater detail in Volume II. The equipment required for full mission accomplishment was provided considering the following major avionics subsystems:

- Communications and Identification
- Air Data System
- Flight Control System
- Sensor Units (Radar and EO/Laser Search and Track Set)
- Mission Computer
- Navigation
- Tactical Electronic Warfare System
- Flight and Engine Instruments
- Warning and Caution, Lighting, and Built-in-Test
- Weapons Delivery

SECTION III

CONTROLLER LOCATIONS - DESIGN APPROACH

The design approach employed in this study involved developing a matrix of possible controller location options and mechanization concepts. This matrix was then critically reviewed to insure that the designs were practicable. Those configurations which appeared promising were subjected to an engineering/human performance evaluation. Two configurations were selected for modeling and formal evaluation. The controller concepts developed during the Reference (4) study were also evaluated here to provide a basis of comparison in both the design and test phases.

LOCATION ALTERNATIVES

A total of seven controller location/mechanization concepts were the subject of an engineering evaluation process. Four of these concepts were new designs which had not been previously evaluated. The four new configurations evolved from a preliminary evaluation which considered mounting location, grip position, and mechanization.

Preliminary Evaluation

For aircraft mounted controllers three basic mounting locations are apparent. These locations, listed in Table 4, have both advantages and drawbacks related to restrictions in panel access, installation complexity, and installation volume. The grip position, grip motion during articulation, and mechanization also influence the viability of a given option.

TABLE 4
CONTROLLER LOCATION/MECHANIZATION OPTIONS

MOUNTING LOCATION	GRIP POSITION	MECHANIZATION
FORWARD INSTRUMENT PANEL	LONGITUDINAL	o FIXED o VERTICAL TRAVEL
	OVER-THE-LAP	o VERTICAL TRAVEL
SIDE CONSOLE	LONGITUDINAL	o FIXED o VERTICAL TRAVEL
	OVER-THE-LAP	o VERTICAL TRAVEL
SILL	LONGITUDINAL	o FIXED o VERTICAL TRAVEL
	OVER-THE-LAP	o VERTICAL TRAVEL

Mounting the controllers on either the forward instrument panel or side consoles provides essentially the same end result in both appearance and grip location. The controllers can be either fixed during seat articulation or move in harmony with the seat. Through added mechanization the grips can be located over-the-lap of the pilot to potentially improve the pilot/controller orientation. The primary advantage of the instrument panel mounting (over console mounting) is a more direct tie to primary aircraft structure. However, for actuator driven controllers, integrating the required mechanization is facilitated by console mounting, which provides adequate volume for installation.

Sill mounted controllers which articulate with the seat were investigated for both the longitudinal and the over-the-lap positions. Due to the mechanization complexity necessary to maintain proper pilot/controller orientation in conjunction with the limited clearance between the seat and sills in the reclined position these concepts could not be satisfactorily mechanized. They may have some merit for a wider cockpit sill and greater seat/sill clearance.

The four configurations which were selected for engineering evaluation are:

- o Instrument Panel Mount with Vertical Adjust
- o Console Mount-Vertical Travel
- o Console Mount-Over-the-Lap
- o Instrument Panel Mount-Fixed

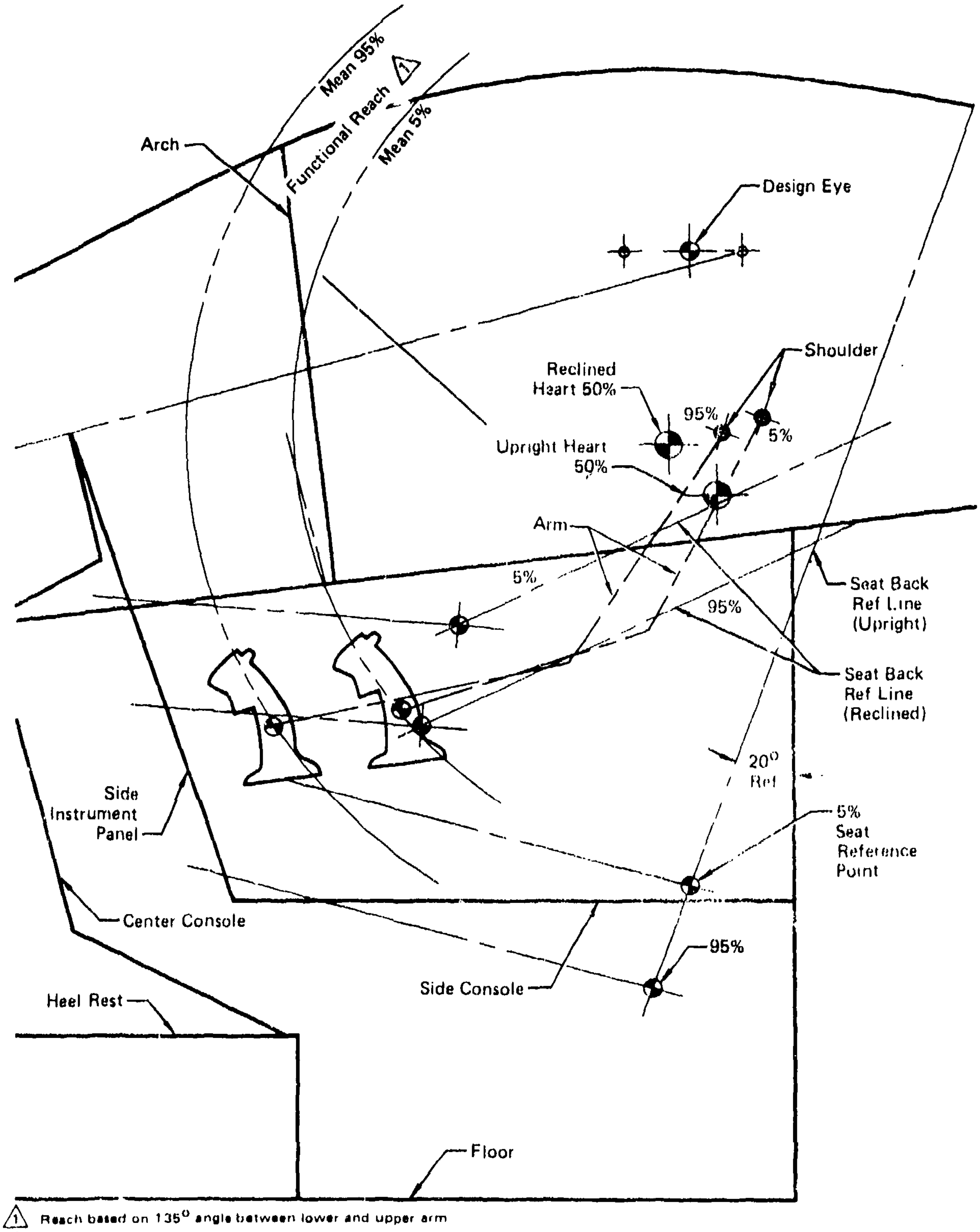
The selection of instrument panel mounting or console mounting does not affect the design aid modeling. It does however reflect the probable major structural tie-in points for an actual aircraft installation.

Configuration Description

The four selected controller location mechanization concepts were evaluated in sufficient detail to permit assessment of visual masking, complexity, and related installation/pilot performance factors. Profile drawings illustrating the grip positions for each configuration were prepared to insure a thorough engineering evaluation of each configuration. During this assessment, three of the controller concepts described in Reference (4) were included to provide a basis of comparison with previous study results. These three configurations retained included two seat mounted concepts (longitudinal and over-the-lap) and fixed console mounted controllers.

Configuration A - Fixed Console Mounted - This configuration was evaluated in the formal test phase of Reference (4). The grips are located below the sills with fore and aft adjustment capability as shown in Figure 6. The full forward position and full aft position correspond to the reach capabilities of 95th and 5th percentile pilots respectively.

Nominal reach envelopes for 5th and 95th percentile pilots are shown, based on maintaining an angle of 135° between the forearm and upperarm. Per MIL-STD-1472B (Proposed), included angles from 120° to 150° represent near maximum arm force exertion capability and may therefore correspond to minimum



1 Reach based on 135° angle between lower and upper arm

2 Horizontal adjust only

FIGURE 6
FIXED CONSOLE MOUNTED CONTROLLERS
Configuration A

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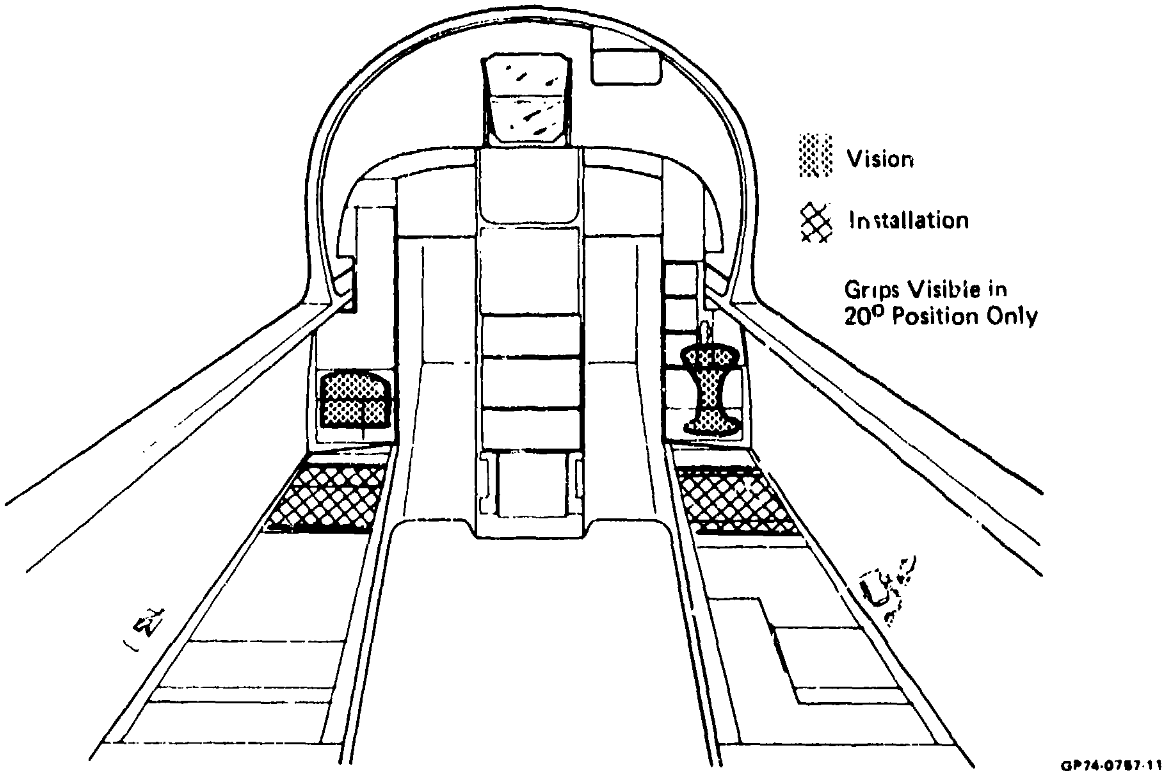
pilot effort and fatigue. The limits of adjustment for Configuration A correspond to an included arm angle of 135° for the extremes of pilot arm length. The position of the heart (in both seat positions) is also identified in this profile view. This was used to assess any tendency toward blood pooling in the arms.

Visual interference caused by the controller grip is shown in Figure 7 together with approximate console space required for controller installation. The visual restrictions for the seat/man combination are not shown. This factor is essentially constant for all configurations and, therefore, need not enter into a comparison of concepts.

Configuration B - Over-The-Lap - Seat Mounted - This configuration was also evaluated in Reference (4). The grips are mounted on arm rests with the controller pivoted over the lap of the pilot. The pivot point is attached to a four-bar linkage (linkage not illustrated) which maintains a near constant clearance between the arm rest and seat pan during articulation as shown in Figure 8. The mechanism is driven by the seat and does not require additional actuation to synchronize the controller with respect to the seat. As the controllers are mounted over the lap of the pilot, they must be pivoted to the sides prior to seat/man separation. This rotation would occur in the initial stages of the ejection sequence.



Notes:
1. Horizontal Adjust
2. Fixed During Articulation

FIGURE 7
FIXED CONSOLE MOUNTED CONTROLLER
VISION/INSTALLATION
Configuration A

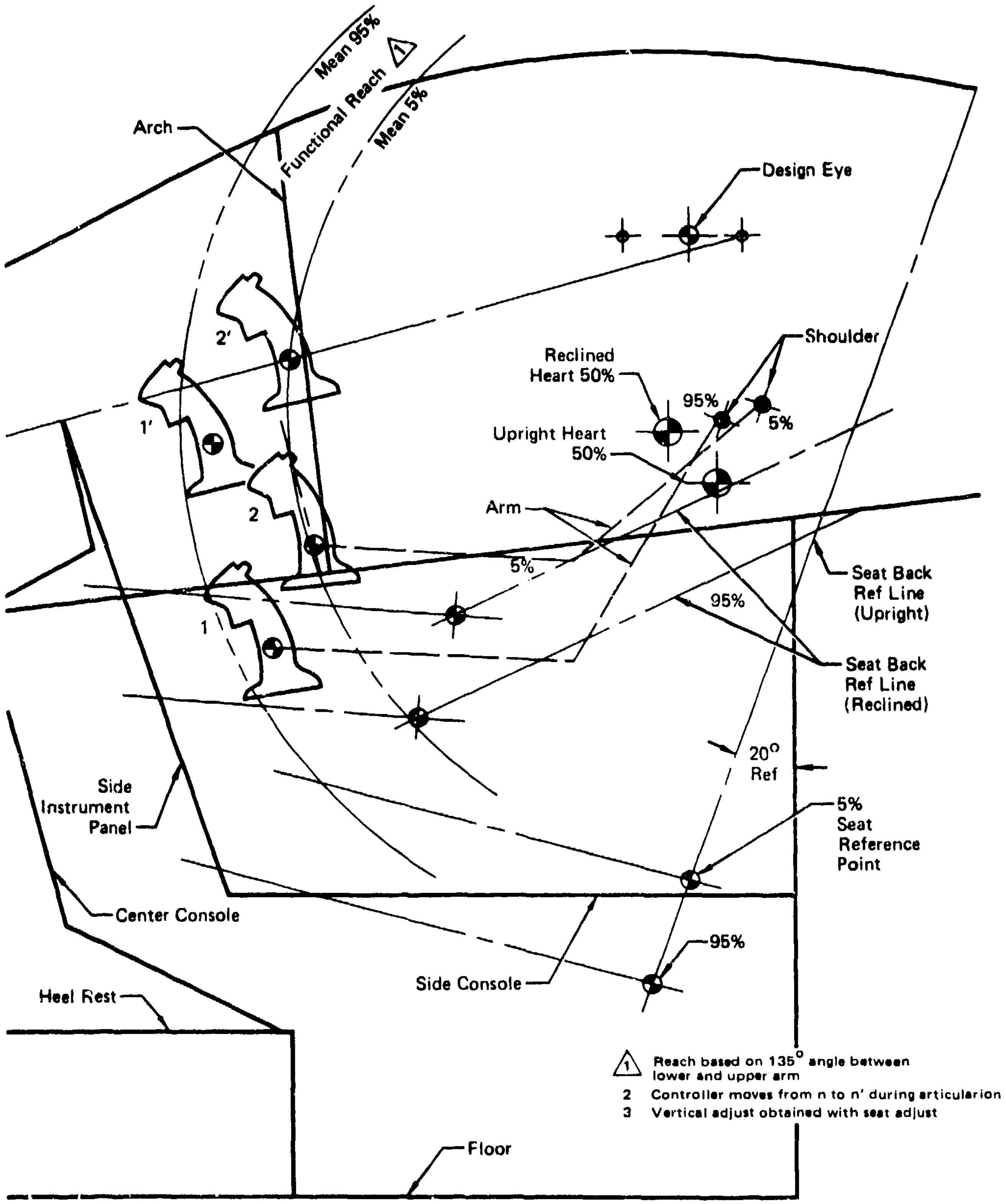
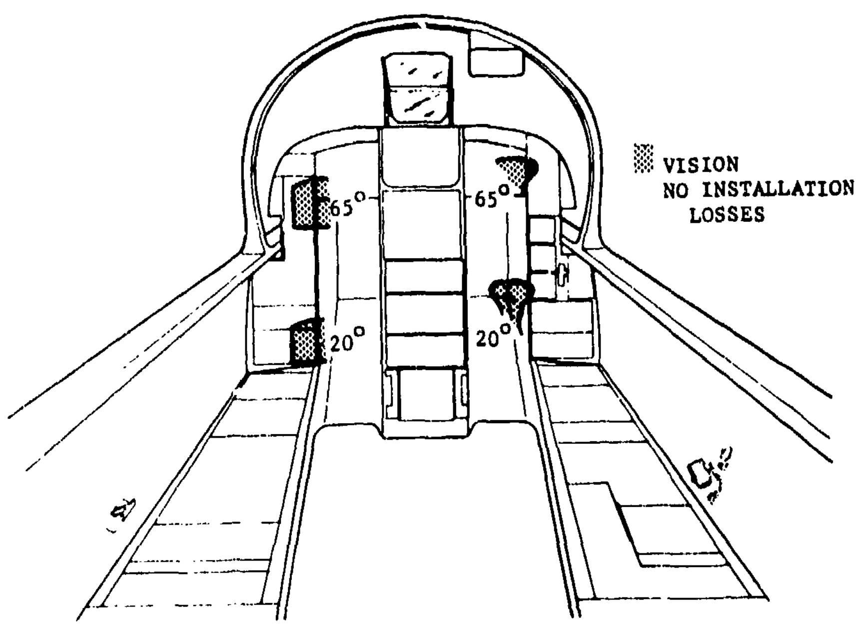


FIGURE 8
SEAT MOUNTED CONTROLLERS
Configurations B and C

Visual interference for this concept is shown in Figure 9. Since the controller mounting mechanization is attached to the seat, no console or panel space is required for installation.

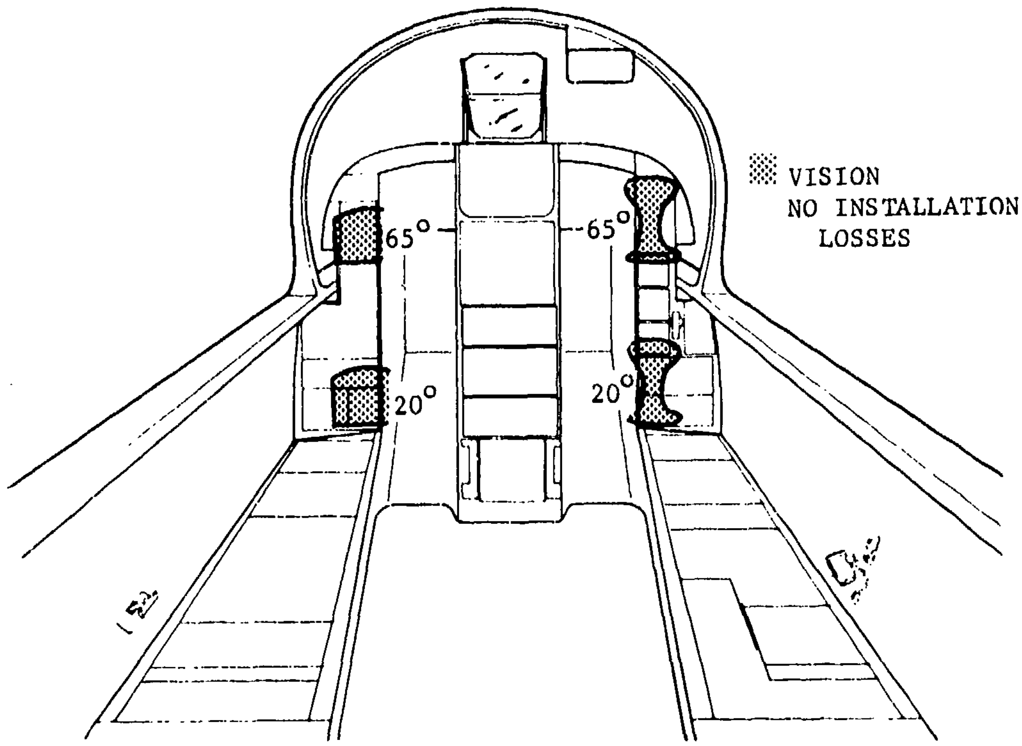
Configuration C - Longitudinal - Seat Mounted - This concept is attached to a similar linkage as Configuration B. This location is also illustrated in Figure 8 with visual blockage shown in Figure 10. Since the grips are longitudinal the ejection sequence is simplified in that the grips need not rotate to the sides, reducing mechanization complexity. This design was also described in Reference (4).

Configuration D - Instrument Panel Mounted with Vertical Adjust - By locating the controllers near the sill line and providing both longitudinal and vertical adjustment the pilot/aircraft orientation can be improved relative to Configuration A. The location/adjustment envelope, shown in Figure 11, can encompass the extremes of a 95th or 5th percentile pilot (sitting height) with 5th or 95th percentile arms respectively while maintaining recommended forearm/biceps angles. Since this configuration does not move during articulation, the visual blockage shown in Figure 12 is the same for both upright and reclined seat positions. This configuration also simulates mounting the grips on a fixed seat bucket with an articulating liner.



Notes: 1. Vertical Adjust With Seat

FIGURE 9
OVER THE LAP SEAT MOUNTED CONTROLLER
VISION/INSTALLATION
Configuration B



Notes: 1. Vertical Adjust With Seat

FIGURE 10
LONGITUDINAL SEAT MOUNTED CONTROLLER
VISION/INSTALLATION
Configuration C

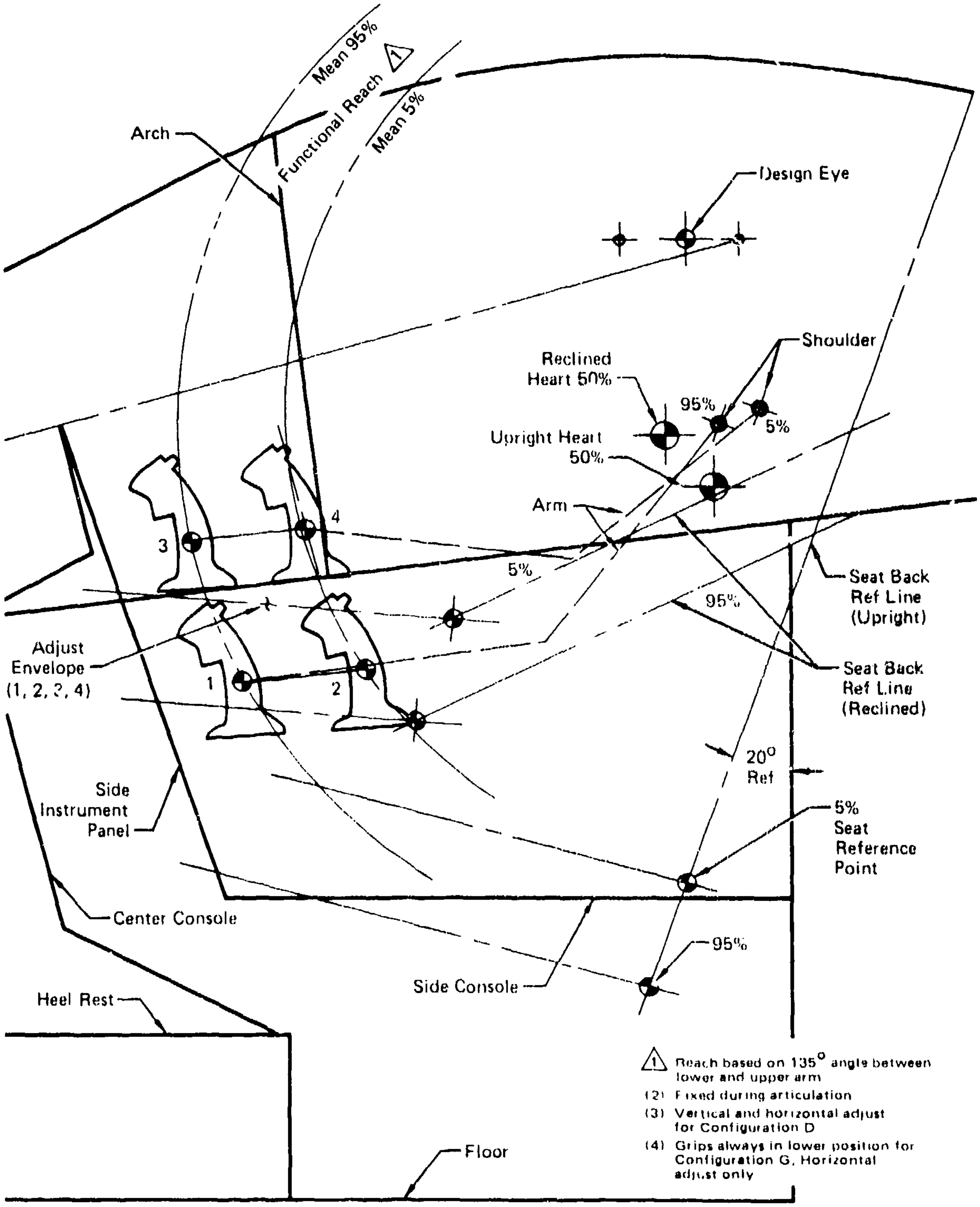


FIGURE 11
INSTRUMENT PANEL MOUNTED CONTROLLERS
Configurations D and G

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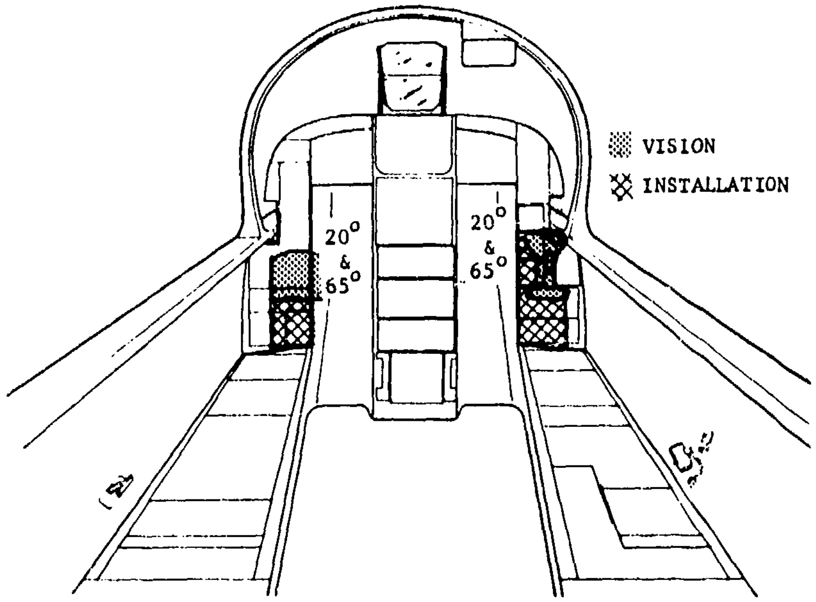

Notes: 1. Fixed During Articulation

FIGURE 12
INSTRUMENT PANEL MOUNTED CONTROLLER
VISION/INSTALLATION
Configuration D

<u>Configuration E - Console Mounted - Vertical Travel - Longitudinal</u> - This configuration provides essentially the same pilot/controller orientation as Configuration C (Longitudinal - Seat Mounted). The primary difference is in the mounting and drive mechanization. For Configuration E the grips are mounted on vertical actuators which must be synchronized with the seat during articulation. The adjustment range is sufficient to encompass the 5th to 95th percentile pilot range. Grip location with respect to seat position is shown in Figure 13.

Visual interference resulting from the controllers and installation space are shown in Figure 14. No controller motion is required during ejection since the grips are external to the ejection envelope.

<u>Configuration F - Console Mounted - Over-The-Lap</u> - This design was derived by combining the over-the-lap feature of Configuration B with the actuation scheme of Configuration E. Pilot/controller orientation is essentially the same as for Configuration B and is shown in Figure 13. The grips are located over the pilot, therefore ejection sequencing must include a rapid rotation of the controllers and mechanization to permit pilot/seat egress. Visual and installation effects are illustrated in Figure 15.

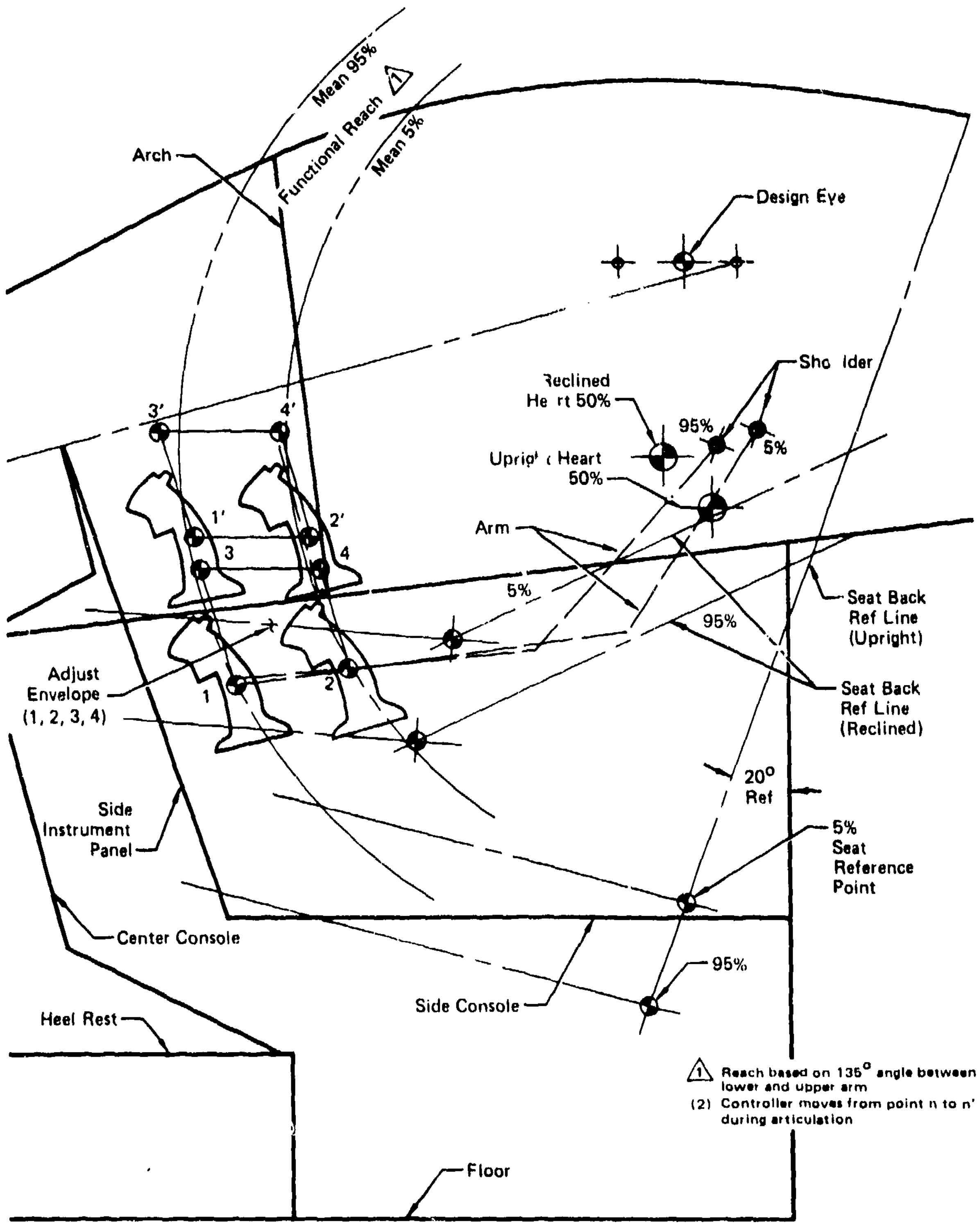

FIGURE 13
CONSOLE MOUNTED CONTROLLERS
Configurations E and F

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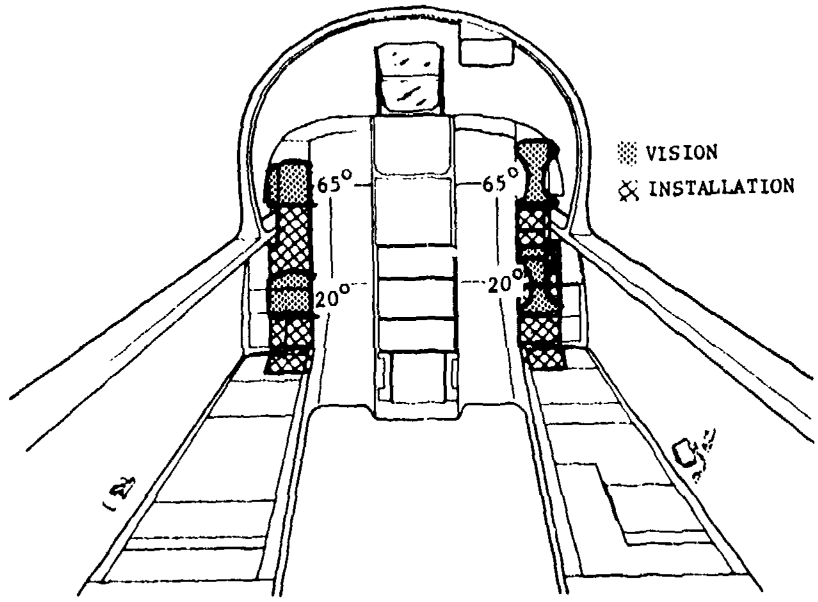
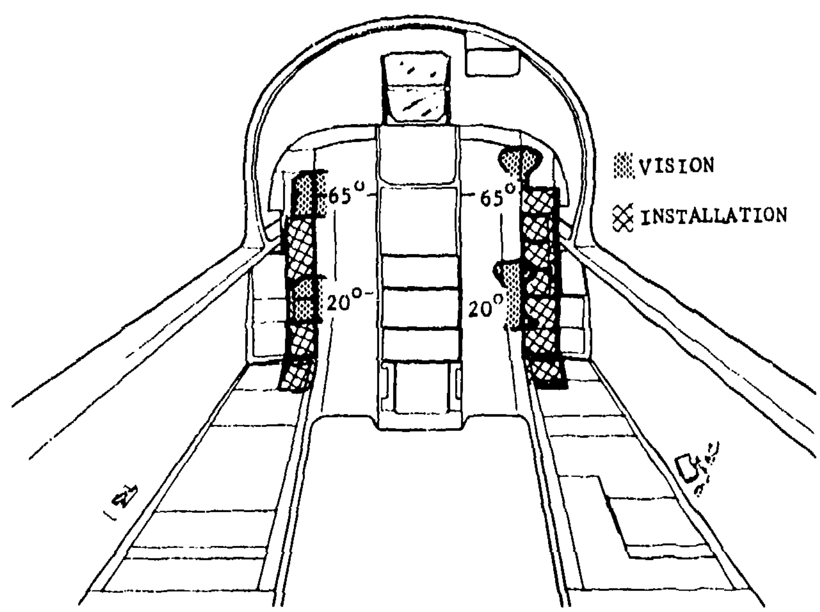


Notes: 1. Vertical and Horizontal Adjust
2. Vertical Travel During Articulation

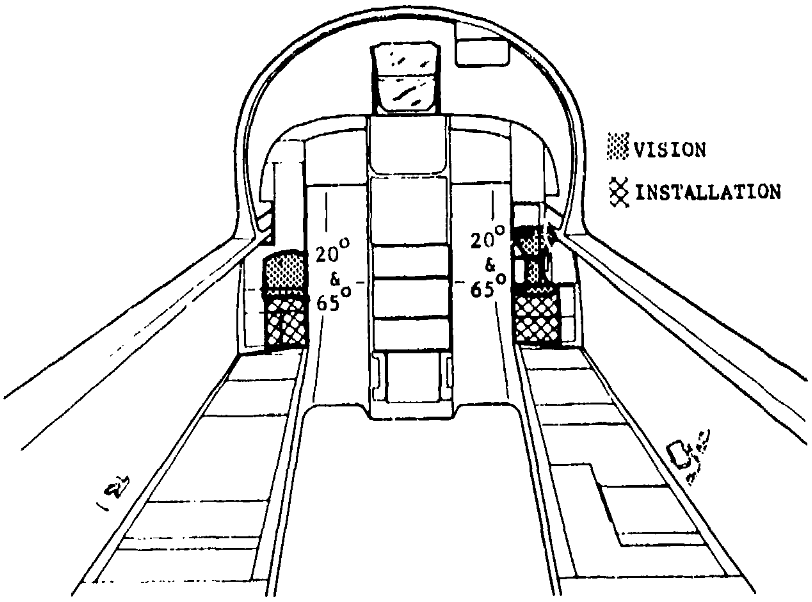
FIGURE 14
LONGITUDINAL CONSOLE MOUNTED CONTROLLER
VISION/INSTALLATION
Configuration E



Notes: 1. Vertical and Horizontal Adjust
2. Vertical Travel During Articulation

FIGURE 15
OVER THE LAP CONSOLE MOUNTED CONTROLLER
VISION/INSTALLATION
Configuration F

Configuration G - Instrument Panel Mounted - This configuration is illustrated in Figure 11. It is similar to Configuration D except it does not have vertical adjustment capability. The vision masking and installation areas are shown in Figure 16.



Notes: 1. Fixed During Articulation

FIGURE 16
INSTRUMENT PANEL MOUNTED CONTROLLER
VISION/INSTALLATION
Configuration G

CONFIGURATION SCREENING

The seven controller concepts were evaluated based on a set of nine parameters. A paired comparison questionnaire was used to determine the relative importance of the nine parameters. The questionnaire was completed by seven design engineering and human performance evaluators intimately familiar with the high acceleration cockpit background and design approach. The parameters are listed below in the priority order assigned by the evaluators together with a brief description of each.

1) Ejection Provisions - Evaluation of the impact of ejection required an assessment of minor encroachments into the ejection envelope, redundant mechanization to insure safe escape, and the impact of the concept on ejection seat design and escape procedures.

2) Pilot/Controller Orientation - When considering pilot/controller orientation the relative placement of the controllers with respect to the pilot was assessed for both seat positions. This is an engineering judgement factor which related the controller locations relative to current practice (center stick/console throttles).

3) Durability and Maintainability - When evaluating this factor the basic mechanization was assessed as well as the probability of inadvertent damage to the mechanization occurring.

4) Mechanization Complexity - It is obviously desirable to minimize the complexity of any mechanization necessary to provide proper controller access/orientation. This includes separate mechanization needs for controller adjustment, degrees of motion, and degree of travel in each direction. This parameter was, therefore, a tradeoff against item 2.

5) Reach Capability - This parameter is similar in nature to vision, in that the utility of the cockpit is a function of what the pilot can readily reach, and what he is required to reach as a function of seat position and control mode. Again the priority of the restricted area was evaluated to arrive at a ranking.

6) Visual Capability - The concepts, to varying degrees, interfere with the pilot's capability to view the interior of the crew station and/or the outside world. Specific assignments of control/display location within the crew station requires a higher degree of visual contact for certain areas. Therefore, the priority of the area blocked (as well as the total area) was evaluated. It should be realized that some blockage can be accommodated by repositioning instruments and secondary controls. Consideration was also given to those controls/displays used as a function of a specific seat position.

7) Alleviation of Blood Pooling - This is a direct measure of the vertical distance between the grip and heart, indicative of any tendency towards blood pooling in the hand and forearm.

8) Installation Penalties - This parameter pertains to that amount of physical panel space lost due to installation of the controller and associated mechanization, with consideration of the relative importance of the specific area lost.

9) General Applicability - Would a specific concept have broad application potential for current and future aircraft systems as well as the current design aid.

These nine items were used to select two new controller/mechanization concepts for evaluation. Items 2, 5, 6, and 7 were evaluated for both upright (20°) and reclined positions (65°).

The aggregate relative importance of these parameters for establishing crew station design interface is presented in Figure 17. If a parameter would have been universally considered the most important by all evaluators it would have received a weighting factor of 8.0. The Kendall's coefficient of concurrence (W) was calculated to be 0.44; which, for the sample size, is significant beyond 0.01. This indicates a high level of agreement between the evaluators opinion as to the relative importance of the evaluation parameters.

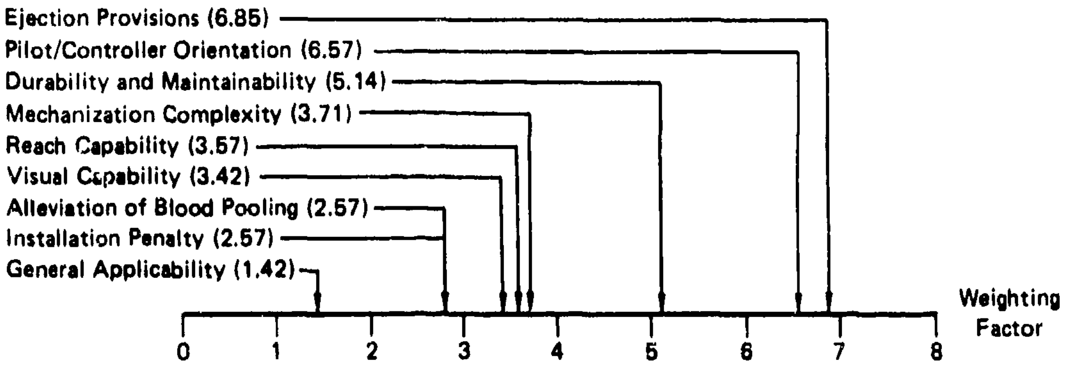


FIGURE 17
CONTROLLER LOCATION
Evaluation Parameters

The seven configurations were then submitted to the same group of evaluators. Each configuration was compared against all others for each evaluation parameter and arranged in descending order. The "best" design, considering a particular parameter, was given a "seven" rating as compared to a "one" for the least desirable design. Ties between different designs were permitted. The individual ratings were summed and weighted according to the previously determined weighting factor. The net result of this evaluation is summarized in Figure 18 for the new configurations.

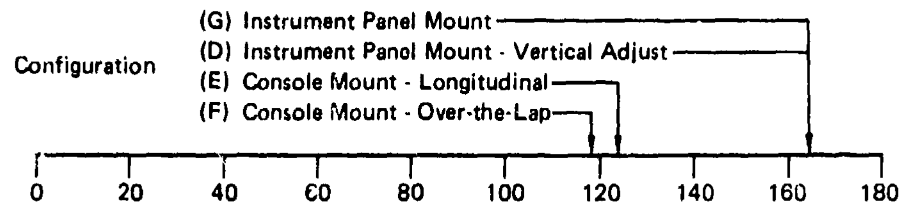


FIGURE 18
CONTROLLER LOCATION RANKING
New Configurations

Configurations D and G received nearly identical ratings and are also similar in location and design. Both are instrument panel mounted with fore and aft adjustment capability. Configuration D includes an additional provision for vertical adjustment. With this added capability Configuration D was selected as one of the new designs for evaluation.

Ejection considerations, mechanization, and reliability were the driving factors in the ranking of Configuration E over F. Based on the higher ranking of E it was selected as the second concept for evaluation.

For the three previously evaluated configurations the rating results are shown in Figure 19. Ejection considerations, mechanization, and reliability are the primary factors which caused Configuration C to be rated higher than B. Additionally, during MCAIR flight simulation using an articulating seat, participating pilots expressed a preference for maintaining the forearms in a waterline plane. With Configuration C, maintaining a horizontal forearm is practical. The controller grips need not be raised to provide leg clearance, as is necessary for Configuration B. In comparing A and C, the improved pilot orientation, lower visual restrictions, and reduced installation penalties of C offset its increased complexity and ejection consideration. Although Configurations A and C rank highest, Configurations A and B were evaluated during the formal testing. Configurations A and B were retained from the Reference (4) study to provide a baseline for evaluation of the new configurations (D and E). The four configurations encompass a wide range of pilot comfort, complexity, escape provisions, and visual restrictions.

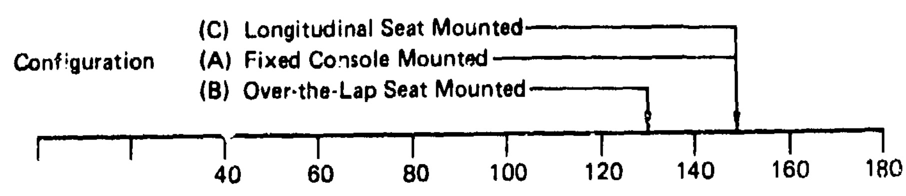


FIGURE 19
CONTROLLER LOCATION RANKING
Reference (4) Configurations

SELECTED CONFIGURATIONS

The four controller locations selected for design aid modeling and subsequent pilot evaluations are listed in Table 5.

TABLE 5
SELECTED CONTROLLER LOCATIONS

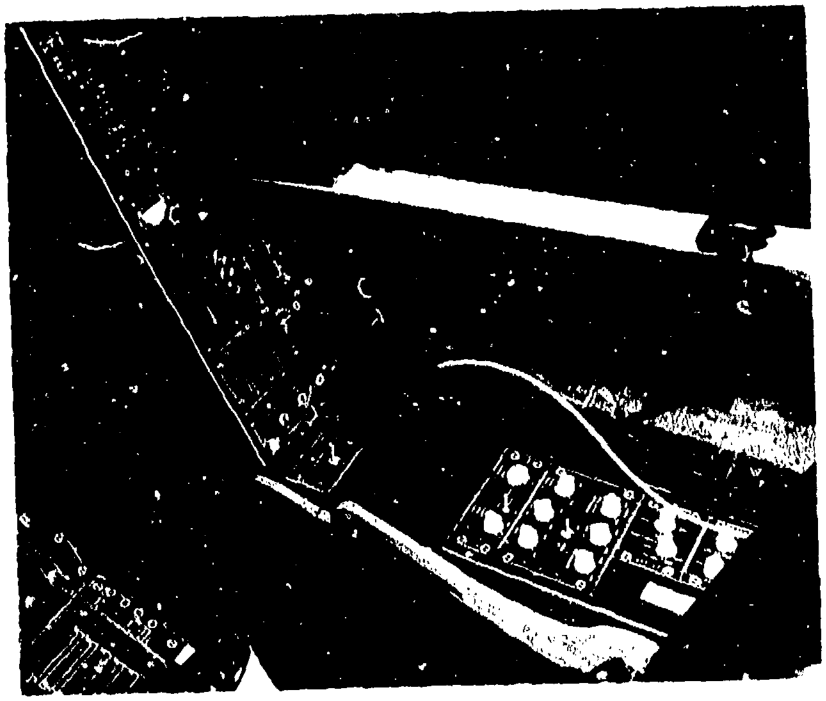
CONFIGURATION	DESCRIPTION	ADJUSTMENT
A	Fixed Console Mount	Fore and Aft
B	Seat Mount Over-The-Lap	Vertical with Seat Adjustment
D	Instrument Panel Mount	Fore, Aft, and Vertical
E	Console Mount Longitudinal (Vertical Travel)	Fore, Aft, and Vertical

Configuration A

The fixed console mounted controller concept represents the most desirable location in terms of low mechanization and escape. The only mechanization, other than integration of the flight and throttle control functions, is fore and aft adjustment. The flight controller installed in the design aid is illustrated in Figure 20 in both the upright and reclined seat positions. Since the controllers are mounted external to the ejection envelope there is no concern for their interference during ejection. Visual blockage of the front instrument panels is also at a minimum due to the low position of the controller grips. This low position of the controller grips results, however, in marginal controller access in the reclined position and the potential for blood pooling in the hands and forearms. Controller access is further degraded for small percentile pilots with shorter arms when they adjust the seat higher to maintain over the nose vision.

Configuration B

The over-the-lap seat mounted controllers are shown in Figure 21. For ingress and egress the controllers rotate to the sides. The pivot point, which is attached to a four-bar linkage, maintains a near constant clearance between the seat pan and arm rest during articulation. Primary advantages attributed to this concept are pilot comfort, controller access, and minimum impact on secondary control/display layout. The arms are supported in what is considered a near natural resting position with the hands near the heart level.



Upright

Reclined

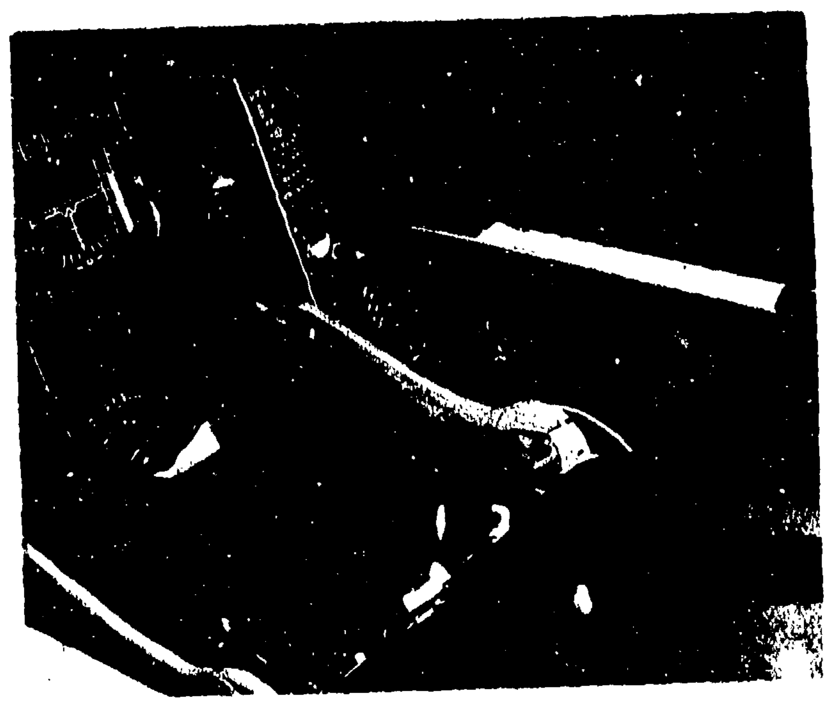


FIGURE 20
DESIGN AID/CONTROLLER INTEGRATION
Configuration A

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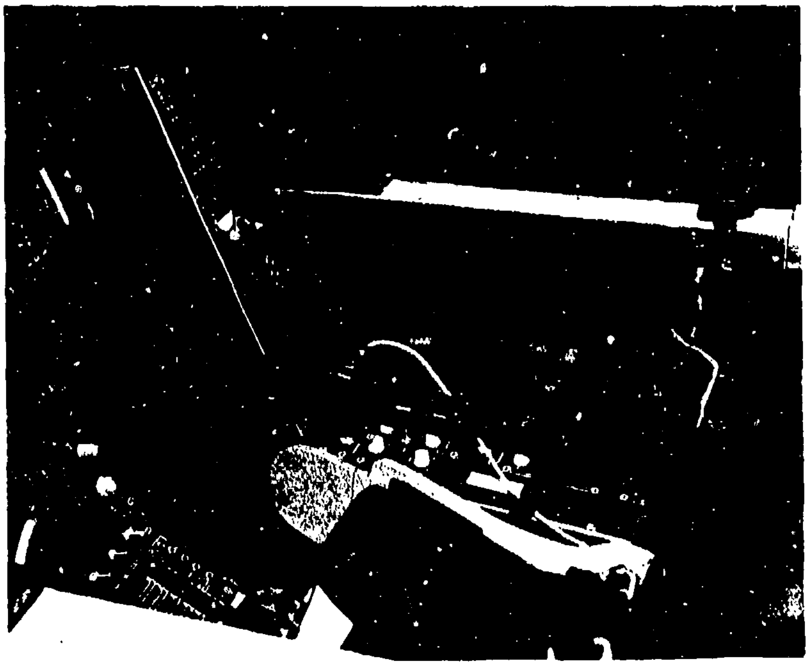

Upright

Reclined

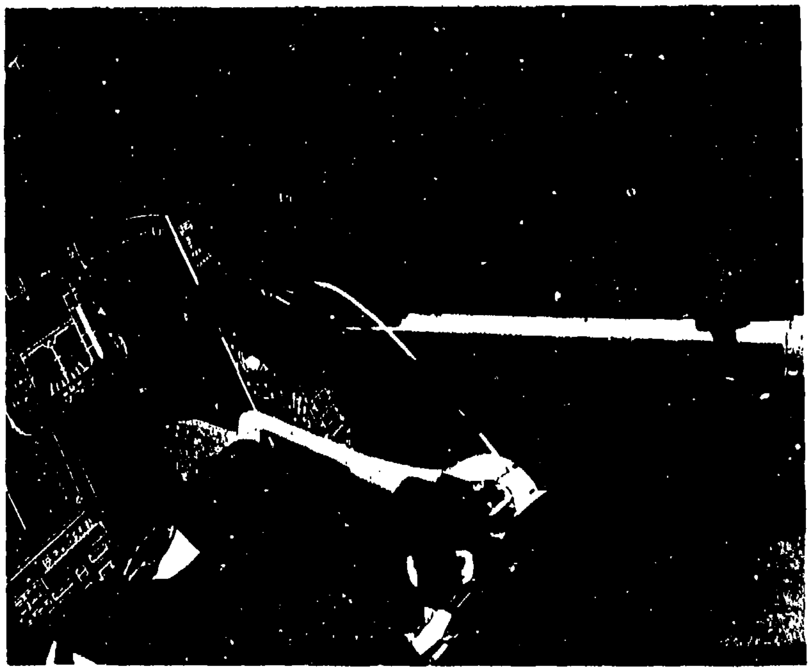

FIGURE 21
DESIGN AID/CONTROLLER INTEGRATION
Configuration B

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For the flight controller the over-the-lap feature places the controller grip as close as practical to the aircraft centerline without blocking vision of the center console. This near center location appeals to pilots who have used a center stick for many years. It should be noted, however, that in numerous informal conversations with pilots who have flown aircraft with human engineered (adjustable position, close to the seat side) side sticks coupled with proper control laws reveals no difficulty in either controller access or control of the aircraft. Adaptation to side sticks appears to require only a short training period.

By mounting the controllers on the seat there is no impact on available panel or console space for secondary control/display placement. This seat mounting does present one of the major drawbacks of Configuration B in that the mechanization complicates ejection seat design and adds to ejection seat weight. The over-the-lap feature also complicates ejection sequencing in that the controllers must be rotated to the sides prior to seat/man separation. For smaller pilots where the seat is adjusted towards the upper limit, the grip/hand combination restricts the external vision to a minor degree. The restrictions, although small, are located immediately adjacent to the HUD, which is a prime external vision area in an air combat engagement.

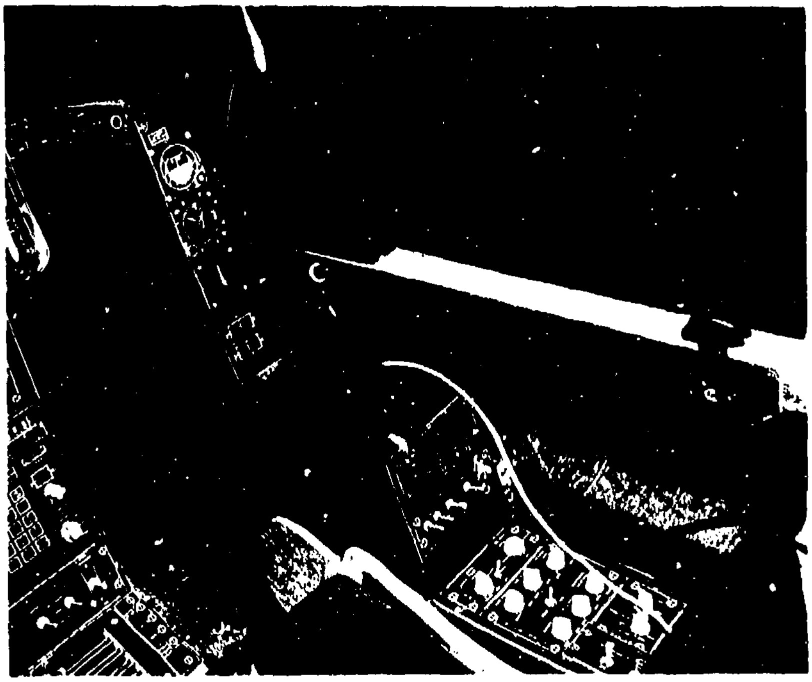
Configuration D

The instrument panel mounted concept was designed to maintain the advantages of Configuration A while providing some improvement in the areas of controller access and potential blood pooling. As illustrated in Figure 22, the grips are located higher than in Configuration A. Provisions are included for vertical adjustment in addition to fore and aft adjustment (the grips do not move during articulation).

The vertical adjustment capability is five to six inches and can be set to favor either the upright or reclined seat positions. For some pilots, adjusting the controller to a high position was necessary to eliminate potential interference between the grips and an inflated G suit. If the aircraft sills are approximately one inch further outboard from the current 13 inches (centerline to sill) this potential interference can be eliminated.

The grips are external to the ejection envelope and do not impact ejection sequencing. Seat back mounted arm rests were developed for this configuration. The arm rests, shown in Figure 23, are adjustable vertically to accommodate various arm lengths. As the seat reclines the arm rests move from an unobstrusive position with the seat upright to a position which provides support for the rear 3 to 4 inches of the forearm. The pad is hinged to swing upward, improving access to the side consoles. The pad is mounted on a pivot to accommodate various forearm angles

The drawbacks of Configuration D are: 1) required installation space; and 2) inability to maintain a near constant controller/pilot orientation during articulation.



Upright

Reclined

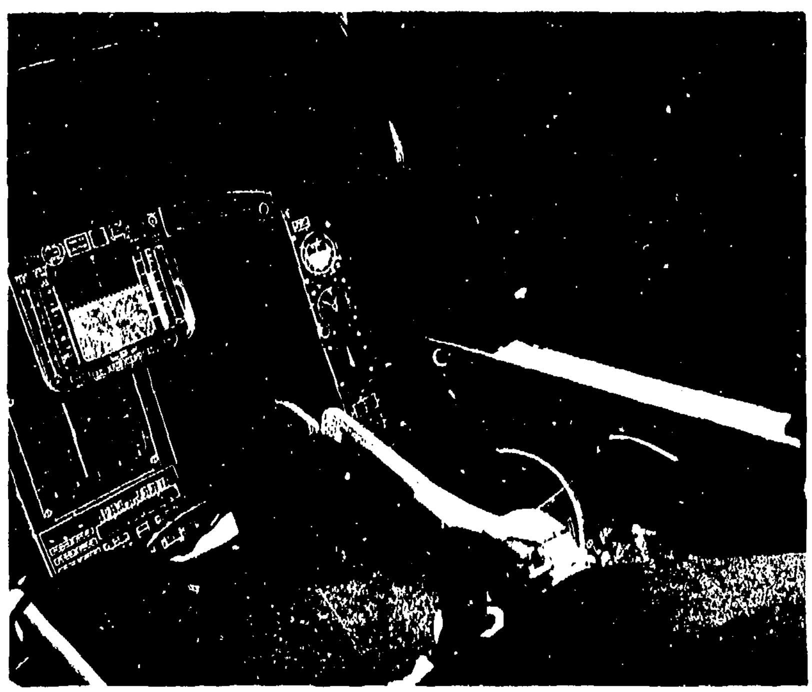


FIGURE 22
DESIGN AID/CONTROLLER INTEGRATION
Configuration D

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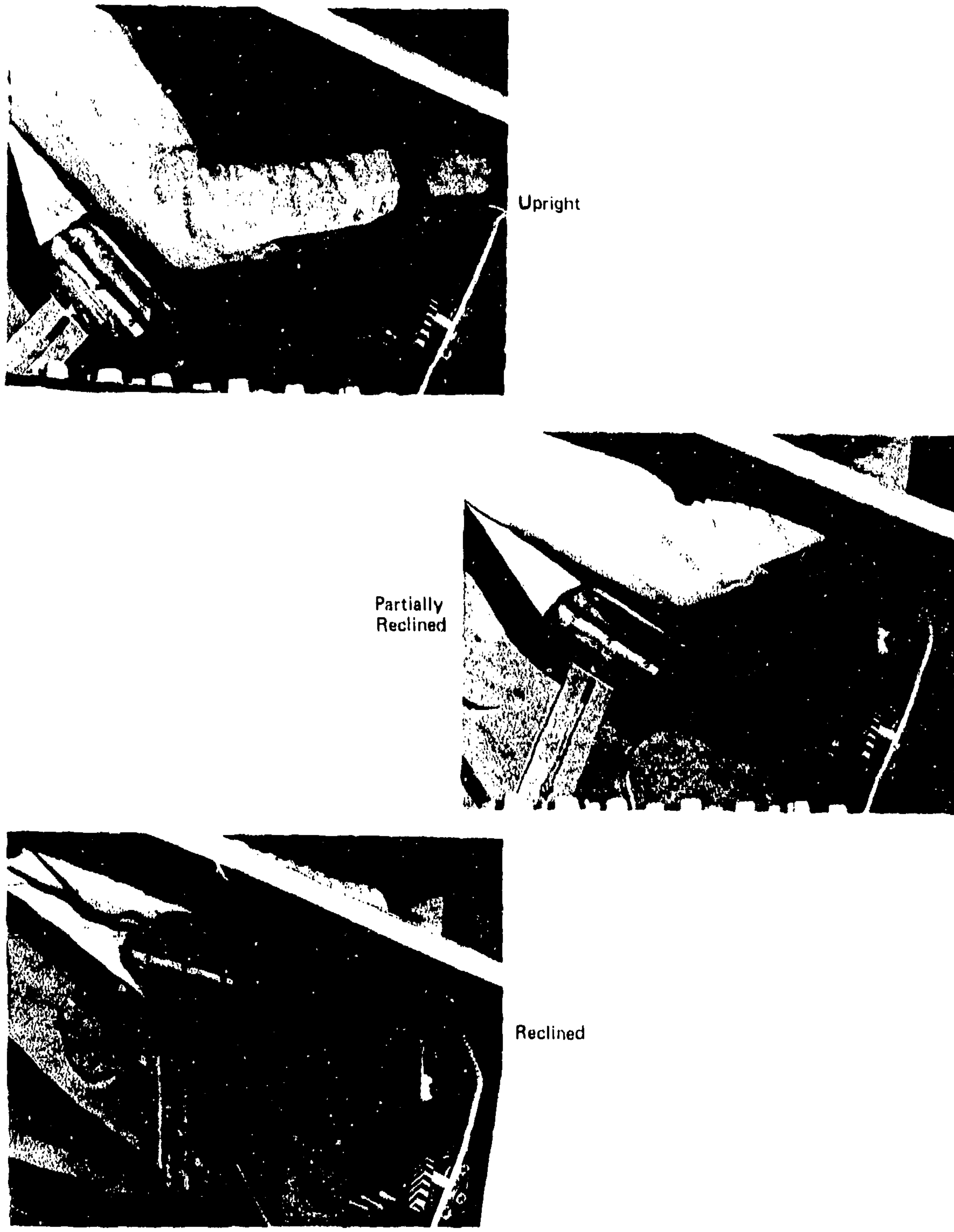

FIGURE 23
ARM REST INTEGRATION

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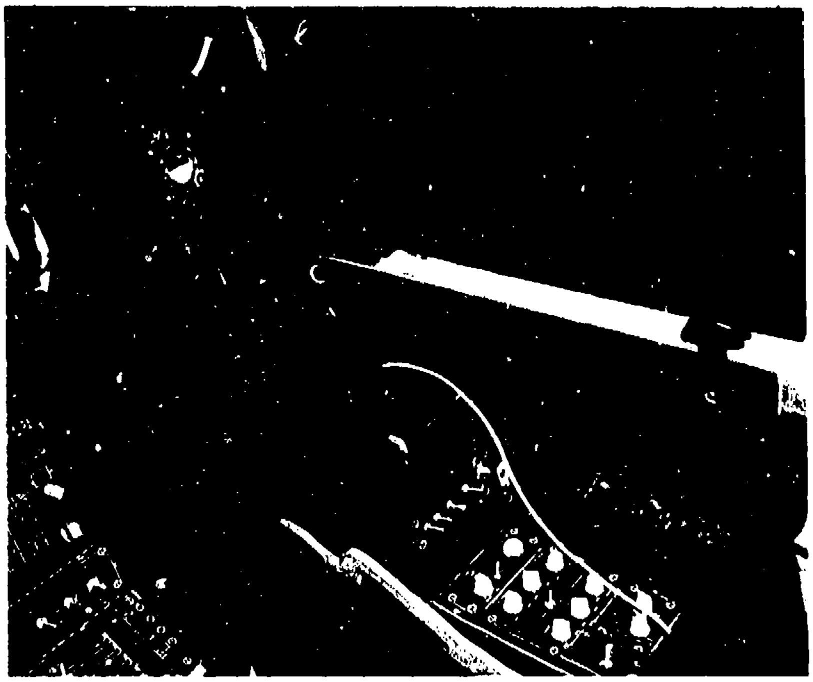
Configuration E

The concept, shown in Figure 24, combines the positive aspects near constant pilot/controller orientation, no ejection interference, and no impact on ejection seat and performance to the maximum extent practicable. The grips are adjustable, both fore and aft and vertically, with an additional six inches of vertical travel during articulation. Because of the vertical travel during articulation the interference between an inflated G suit and the grips, experienced with Configuration D, is eliminated and the orientation and pilot comfort need not be compromised for either the upright or reclined positions. The arm rests described under Configuration D and shown in Figure 23 are also applicable to Configuration E.

The drawbacks of this concept are the required installation space and increased complexity (relative to A and D) to provide the vertical travel during seat articulation.



Upright

Reclined

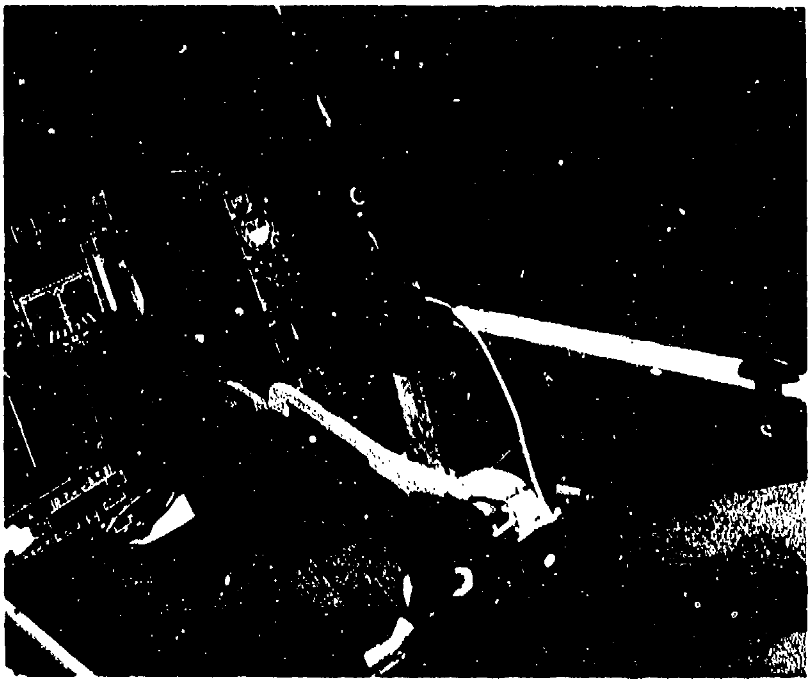


FIGURE 24
DESIGN AID/CONTROLLER INTEGRATION
Configuration E

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SECTION IV

CONTROL/DISPLAY CONCEPTS

An ancillary task associated with the integration of the controller concepts was development of compatible control/display concepts. The location of the controllers, mechanization, and motion during articulation all influence proper control/display layout. Three control/display layouts were utilized which are compatible with the specific controller locations evaluated here. Additionally, two throttle grips and two flight controller grips were considered compatible with the controller locations and related control/display layouts. Compatible controller locations, control/display configurations, flight controllers and throttles are summarized in Table 6.

TABLE 6
CONFIGURATION COMPATIBILITY

CONTROLLER LOCATION	CONTROL/DISPLAY CONCEPT	FLIGHT CONTROLLER	THROTTLE
Fixed Console Mounted (A)	I	Baseline or Integrated	Baseline or Canted
Seat Mounted Over-the-Lap (B)	II	Baseline or Integrated	Baseline or Canted
Instrument Panel Mounted (D)	III	Integrated	Canted
Console Mounted Vertical Travel (E)	III	Baseline or Integrated	Baseline or Canted

CONTROL/DISPLAY REQUIREMENTS

The selected controls and displays provide a significant multi-role capability in a small sized cockpit. The configuration, location and extent of integration is primarily a function of cockpit size, vision and reach constraints, and pilot task requirements for two different seat positions (reclined and normal). Controller locations also influence the controls and displays in that they affect vision, reach, and available panel space.

The required controls and displays are categorized into four major areas related to seat position and mission phase.

- o Reclined Seat Position - Combat
- o Reclined Seat Position - Cruise
- o Upright Seat Position - Cruise
- o Upright Seat Position - Ground

The reclined seat position during combat must integrate with those items which must be available to the pilot for either control or information presentation. Reduced priority is given to the reclined seat position during cruise. It is anticipated that pilots will recline the seat during cruise to some nominal back angle to improve comfort or relieve fatigue. In this position it is also desirable to provide adequate access to normal function if this provision does not compromise higher priority items. Upright seat position during cruise and ground operations are of lower order priorities.

A listing of major controls and displays required for combat, cruise and ground operations is presented in Table 7. This listing together with pilot tasking and workload formed the rationale for the control/display locations. Ground controls such as the Built-in-Test (BIT) and Ground Power panels have been located in those areas remaining after consideration of the more important controls. These are listed in groups of descending priority. For those items which are required in reclined combat, ready access and viewing must be available. Those items which are desirable in reclined combat, or required in reclined cruise, may be located where minor movement is necessary. Correspondingly larger movement is permissible for those items required only during upright cruise. All of the listed controls and displays are required during ground operation for checkout and status checks.

A separate condition was considered to provide the pilot the necessary controls to land the aircraft in the event of a seat failure in the reclined position. Sufficient redundancy should be built into the seat positioning system to permit ejection from the upright position in case of an emergency. The prime requirement in this event is upgrading the landing gear control from a position of "desired" to "required" access in the reclined position.

Those secondary controls which are used during a high percentage of the flight time are clustered on the left side of the cockpit. This location permits left hand operation of the controls while maintaining control of the flight path with the right hand. Similarly the right side has been reserved for displays or little used subsystem controls. This restriction is not as critical for a conventional center stick as the pilot can easily control the aircraft with his left hand while operating secondary controls with his right hand. In the normal seat position all controls and displays are available for utilization. In the reclined position there is a considerable reduction in reachable and viewable areas of the cockpit. However, the cockpit design provides all necessary controls and displays to the pilot that he may require when he is in the reclined position.

PRIMARY FLIGHT CONTROLS

Two different (baseline and integrated) flight and throttle controllers were evaluated in conjunction with evaluating the controller locations. The flight and throttle controllers developed during the Reference (4) study were employed as a baseline for comparisons with the new configurations. The grips are fitted with active switches (force and displacement) to enable evaluation of switch placement in terms of access and ease of operation.

Flight Controllers - The flight controller developed during the previous study is shown in Figure 25. This controller incorporates provisions for the

TABLE 7
CONTROL/DISPLAY REQUIREMENTS

CONTROL/DISPLAY	HIGH G COMBAT	RECLINED CRUISE	UPRIGHT CRUISE AND GROUND OPERATIONS
Flight Controller	R	R	R
Throttles	R	R	R
Weapons Release	R	R	R
Weapons Select	R	R	R
Primary Flight Inst.	R	R	R
Emergency Controls	R	R	R
Comm/IFF/ECM Cont	R	R	R
Fire/Threat Warning	R	R	R
ADI	R	R	R
Gunsight/HUD	R	R	R
Seat Position Switch	R	R	R
Master Caution	R	R	R
Weapon Status	R	R	R
Fuel Status (Bingo)	R	R	R
Gun/Master Arm	R	R	R
Sensor Controls	D	D	R
Avionics Controls	D	D	R
Comm Status	D	D	R
Landing Gear		D	R
Engine Inst		D	R
Auto Flight Cont		D	R
Hydraulic Inst		D	R
Secondary Flight Inst		D	R
Air Refuel		D	R
Caution Lights		D	R
ECS Cont			R
Lighting (Internal and External)			R

R - Required
D - Desirable

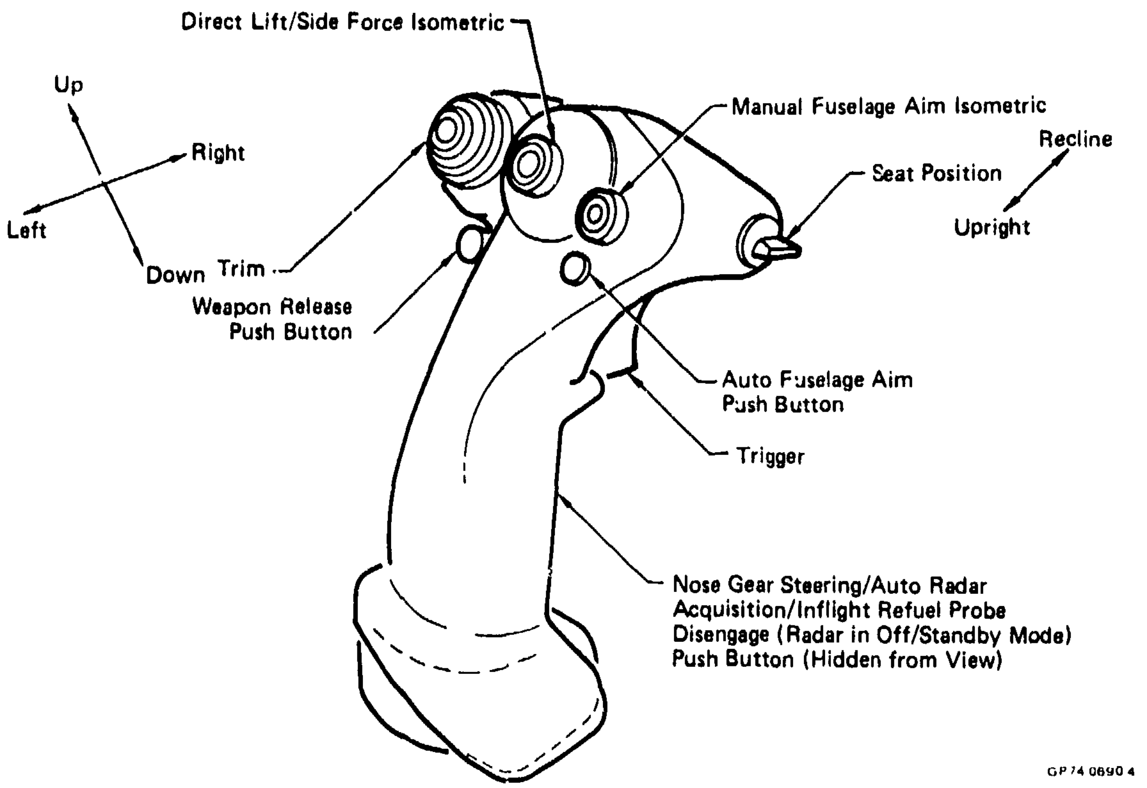

FIGURE 25
FLIGHT CONTROLLER FUNCTIONS
Baseline Design

basic flight control functions (pitch and roll) through force applied to the grip or small angular displacements. Additionally, the following functions are incorporated to provide accessibility and to reduce workload during critical mission phases. Direct lift and side force controls are incorporated in a cupped, isometric thumb control button directly in line with the grip centerline. In-flight trim and manual fuselage aiming are located in an arc scribed by the thumb along the top of the grip. For some advanced fighter concepts, fuselage aiming enables pointing the fuselage at a selected target independent of the flight path of the aircraft. Weapons release and automatic fuselage aim functions are located immediately below this arc. In the automatic fuselage aiming mode the fire control computer aims the fuselage to obtain a weapons release solution without altering the aircraft flight path. The gun trigger is positioned in the normal forefinger location. This trigger has two detents. The first activates the HUD camera and the second initiates gun firing. The HUD camera is also activated upon depression of the weapons release button. A nose gear steering/automatic acquisition mode dual function push button is located on the lower portion of the grip and is activated by the little finger. When weight is on the wheels, this button provides a nose gear steering mode of $\pm 45°$. After gear retraction this push button operates as an automatic radar acquisition mode selector. A two-position switch is provided on the right side for seat control. This control is located on the grip to allow pilot access synchronous with G command and also provide immediate access while the seat is reclined in the event of an emergency situation. This grip design is compatible with controller Locations A, B, and E.

For Configuration D, where the grip is located between the seat sides and aircraft sill, the flight controller was redesigned as shown in Figure 26, permitting retention of a 26" sill width. The redesign primarily centered on reducing the maximum width, thereby providing sufficient knuckle/seat/sill clearance. Removal of the discrete trim control and integration of this function and the fuselage aiming mode function with the isometric thumb controller are the primary design changes. These changes reduced the overall grip width by approximately 3/4 of an inch. Because of the multi-mode isometric, a visual cue on the HUD would be provided to indicate the current operating mode.

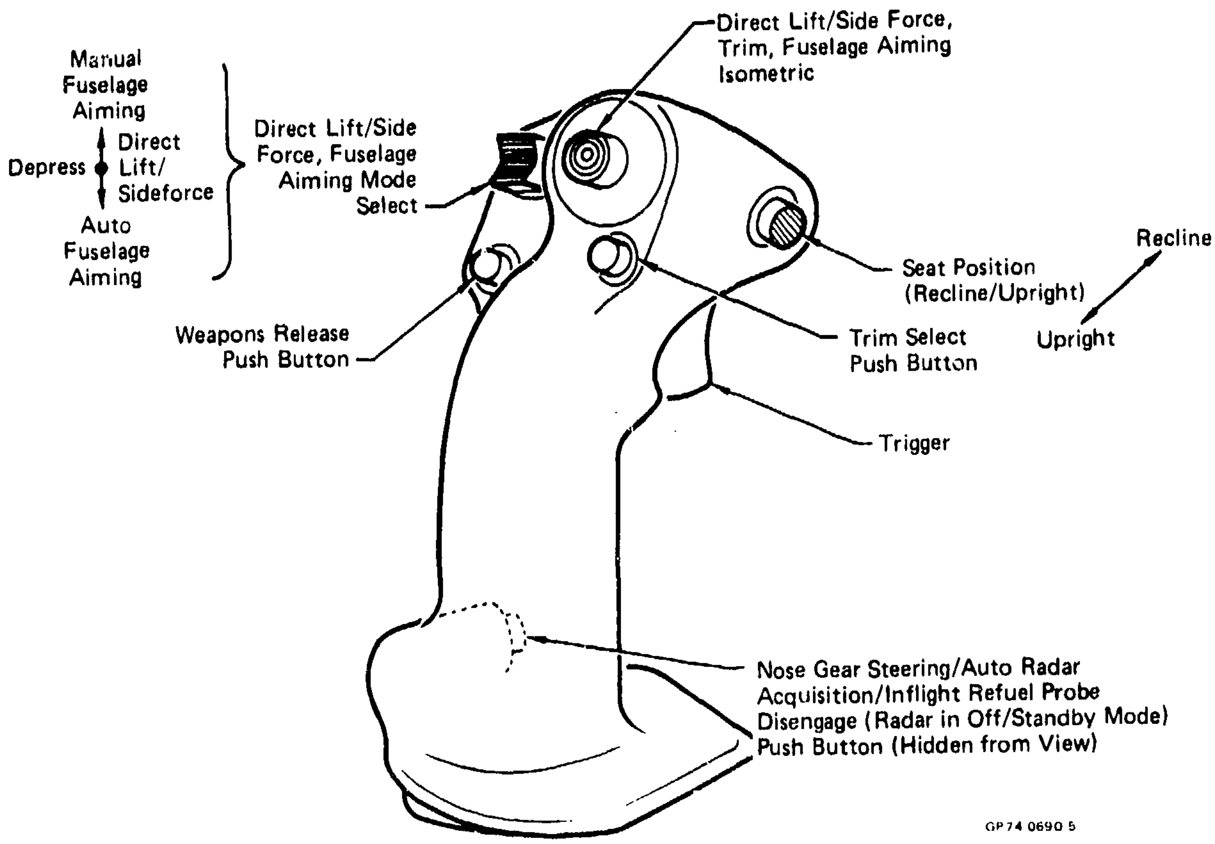

FIGURE 26
FLIGHT CONTROLLER FUNCTIONS
Integrated Design

Transducer enclosures capable of accommodating two types of transducer integration were evaluated for the flight controller. For horizontal integration a rectangular envelope approximately 6 inches long, 3 inches wide, and 2 inches deep, below the controller base, permits mechanization of either a force stick or a displacement stick with moderate angular motion and fore and aft adjustment capability. This envelope was used for all of the configurations evaluated.

An alternate vertical mechanization was investigated for the console and instrument panel mounted controller locations. This envelope, which is 3 inches in diameter and 6.5 inches long (a vertical cylinder below the grip) provides identical capabilities as the horizontal envelope. This design was conceived to reduce visual and reach constraints relative to horizontal integration. However, when fore and aft adjustment mechanization is included, the size of the adjustment mechanization negated the benefits of vertical integration.

Throttle Controllers - The throttle grip developed during the Reference (4) study is shown in Figure 27. By maintaining the throttle motion in a waterline plane, the throttles can be moved by pilot force inputs under both high and low G loading. A radar designator control is mounted on the front of the throttle. As with the flight controller, other control functions are incorporated into the throttle. A three-position weapon/mode select switch and missile/weapon uncage push button are mounted on the side surface of the right throttle. The weapon mode select switch is used to select gun, AIM-9L missiles, or missile reject. When the missile mode is selected and master arm activated, the uncage push button uncages either missiles or bombs depending on programmed flight phase (air-to-air and air-to-ground). For other weapon mode selections, this button provides rudder trim. Finger lift controls are provided for engine cutoff. Five additional controls are located on the throttle to perform the following functions:

(1) Speed brake/modulated drag
(2) Communications - transmit/receive
(3) IFF interrogate
(4) ECM - Chaff/off/special ECM dispenser or flares
(5) Radar elevation

As with the baseline flight controller, the throttles shown in Figure 27 are compatible with controller Locations A, B, and E. For Configuration D it was again necessary to redesign the grip. The overall width of the grip/hand combination for the baseline design is 4.5 inches. By canting the grip at a 35° angle, as shown in Figure 28, the overall width is reduced to 3.5 inches allowing placement between the seat and sill. Functionally, the throttles are identical with those shown in Figure 27.

A transducer envelope approximately 2 inches wide, 2 inches in depth, and 6 inches long immediately below the grip is required to permit mechanization of twin engine split throttles with 3 to 4 inches of linear travel.

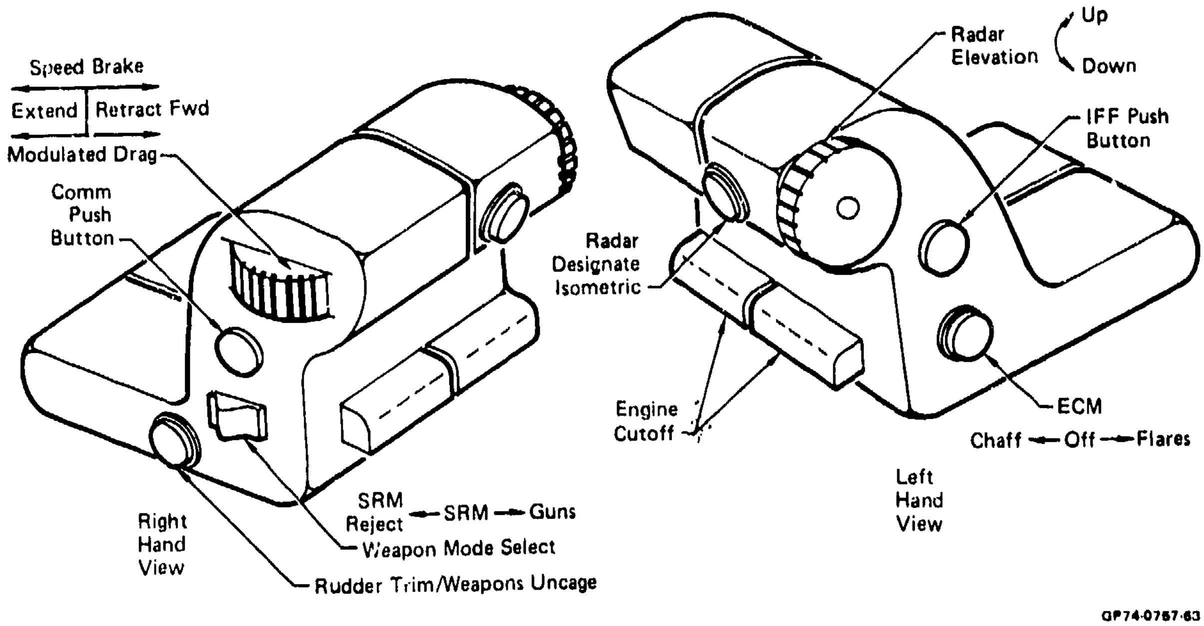

FIGURE 27
THROTTLE CONTROL FUNCTIONS
Baseline Design

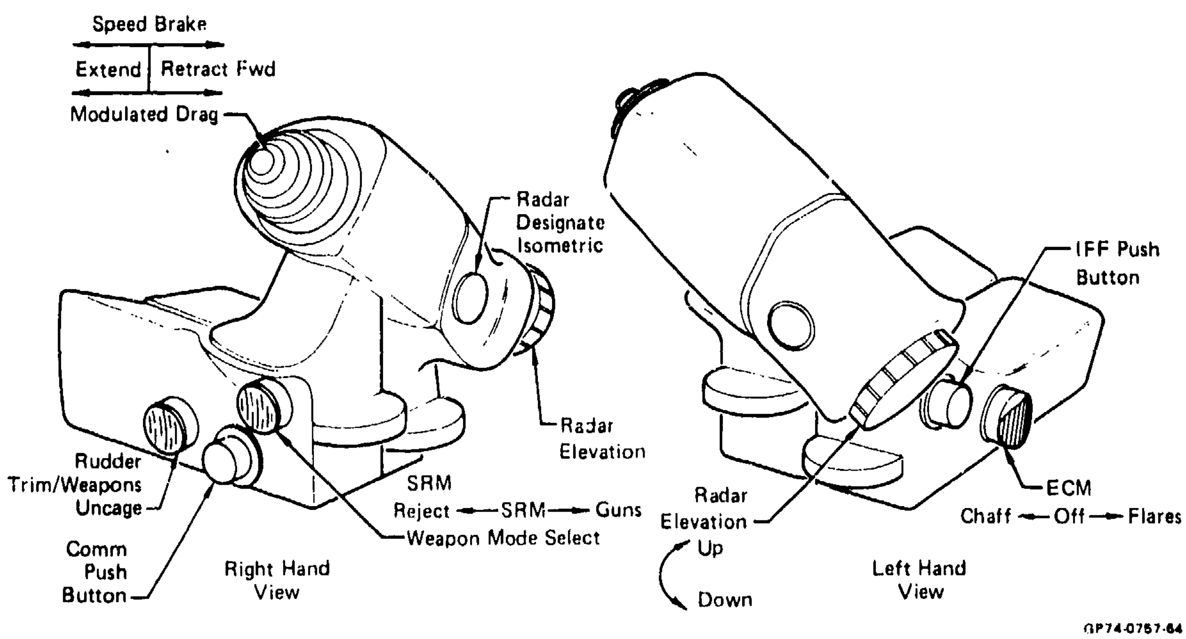

FIGURE 28
THROTTLE CONTROL FUNCTIONS
Canted Grip

CONTROL/DISPLAY CONFIGURATIONS

Three control/display configurations were developed to be compatible with the selected controller locations. Control/Display Configurations I and II are compatible with the Fixed Console Mounted Controllers and Over-the-Lap Controllers respectively. These configurations represent refinements of those developed in Reference (4) and only rationale for changes are reported herein. Control/Display Configuration III is compatible with the two new controller locations. Extensive rearrangement of secondary controls and displays was necessary to accommodate the new controller locations.

Configuration I - Fixed Console Mounted Controller Controls and Displays

The displays and controls for this cockpit arrangement are shown in Figure 29. The functional requirements investigation together with pilot tasking/workload formed the basis for control/display selection and placement in the Reference (4) study. Following the Reference (4) evaluation, the layout was modified to reflect the results of the pilot interaction. The fire control/HUD display master mode control push buttons, master arm and gun fire rate switches, and emergency jettison controls which are located above the left leg cutout, were rearranged to reduce the possibility of accidental switch actuation and improve accessibility.

The warning/caution light panel was relocated from the right leg cutout to the side surface of the left leg cutout. This relocation provided an ideal shadow box area for the addition of a MSD in the right leg cutout. The display functions for the three MSD's and the HUD are presented in Figure 30.

A digital fuel readout was added above MSD-1 and a TCN volume control was added to the left console. These additions were based on pilot recommendations from the previous study.

Configuration II - Overlap Controller Cockpit Controls and Displays

The displays and controls for this cockpit configuration are shown in Figure 31. The modifications to this layout, as compared to Configuration II in Reference (4), are identical to the modification to Configuration I. The addition of the MSD in the right leg cutout provides the capability of four simultaneous displays. The display functions for the four MSD's and the HUD are presented in Figure 32.

Configuration III - Instrument Panel Mounted or Movable Console Mounted Controllers Controls and Displays

The controls and displays were extensively rearranged to accommodate the new controller concepts. The resulting layout, shown in Figure 33, provides essentially the same capability as Configuration I. The MSD functions are identical to Configuration I as presented in Figure 30. The location differences between Configurations I and III are presented in Table 8 including the reasons for each change.

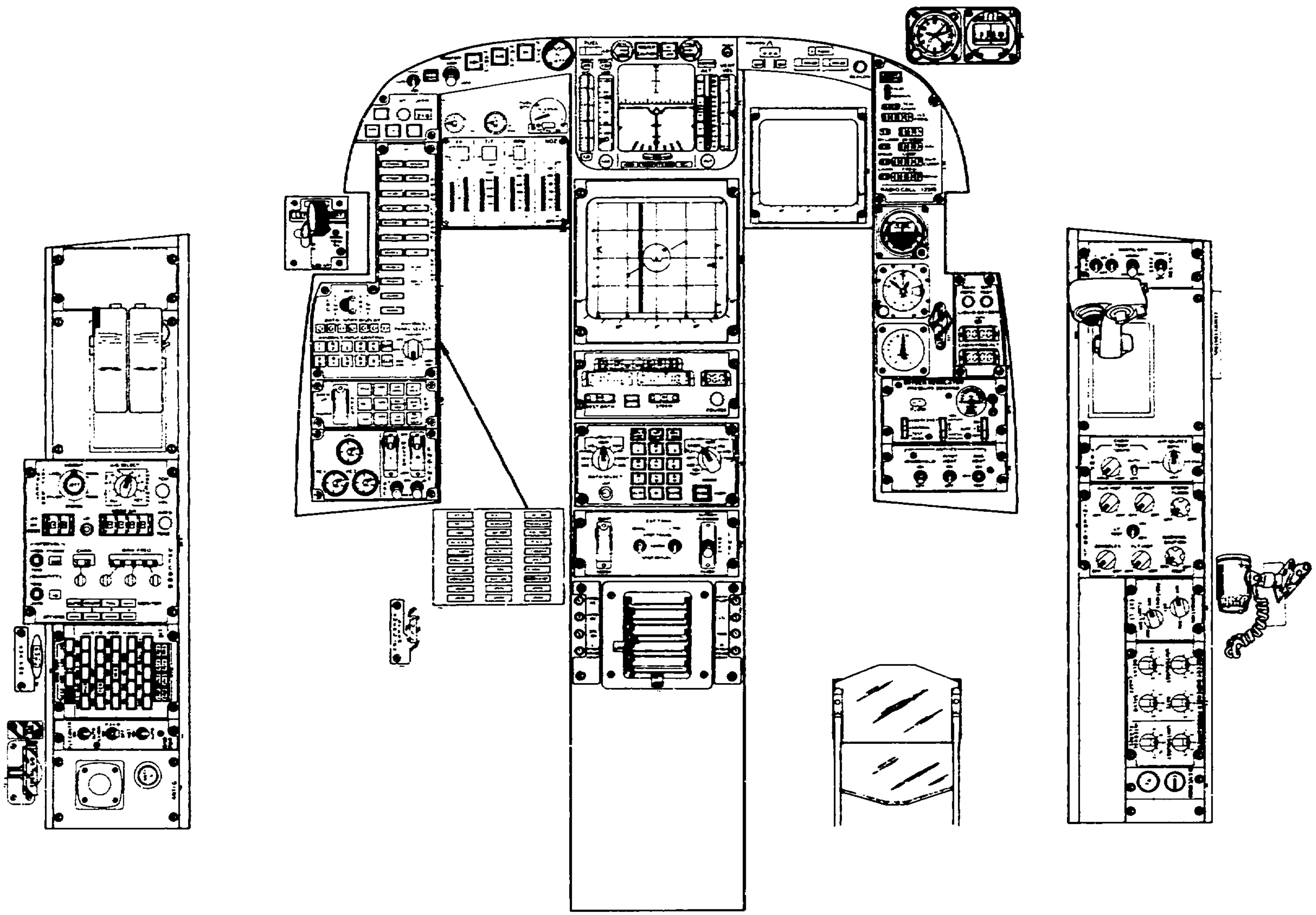

FIGURE 29
FIXED CONSOLE MOUNTED CONTROLLER CONFI ATION
Used With Controller Configuration A
Configuration I

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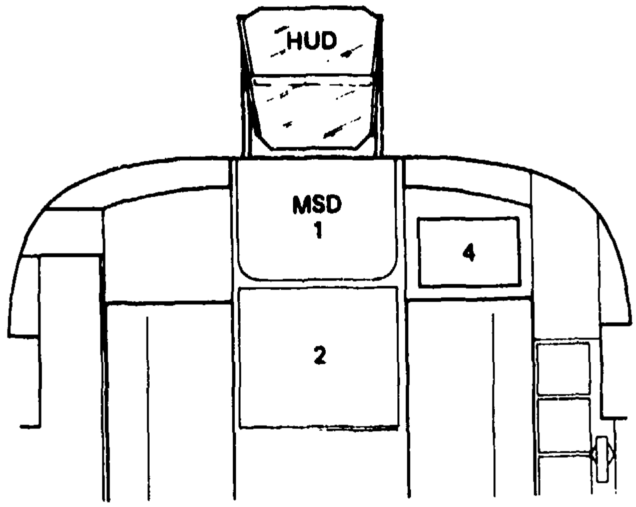

Display		Display Modes
Upright / Reclined	HUD	A/A Attack - Steering and Cues A/G Attack - Steering and Cues NAV - Steering and Cues
Upright / Reclined	MSD-1	RDR - A/A Search, A/A Attack, Ground Map and A/C Ranging TEWS - Exclusively EO - A/A and A/G Under the Nose Visual Aid ADI - Primary Reclined ADI
Upright	MSD-2	RDR - A/A Search, A/A Attack, Ground Map and A/C Ranging EO - A/A and A/G Visual Aid HSD - Moving Map Display with TEWS Overlay
Upright	MSD-4	TEWS - Exclusively EO - A/A and A/G Visual Aids

Note: MSD-3 functions do not apply to this configuration

FIGURE 30
CONFIGURATIONS I AND III DISPLAY FUNCTIONS

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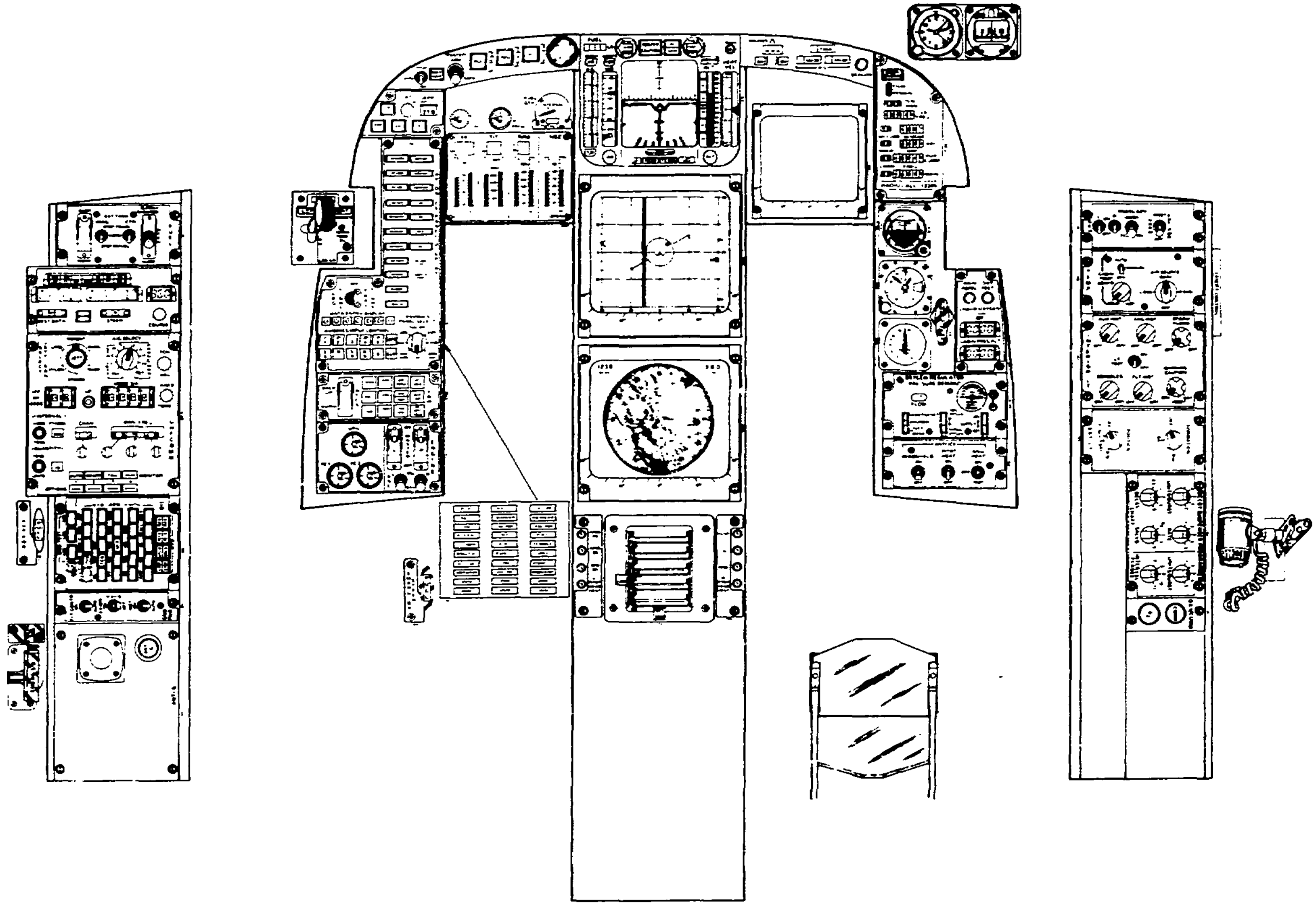

FIGURE 31
SEAT MOUNTED CONTROLLER CONFIGURATION
Used With Controller Configuration B
Configuration II

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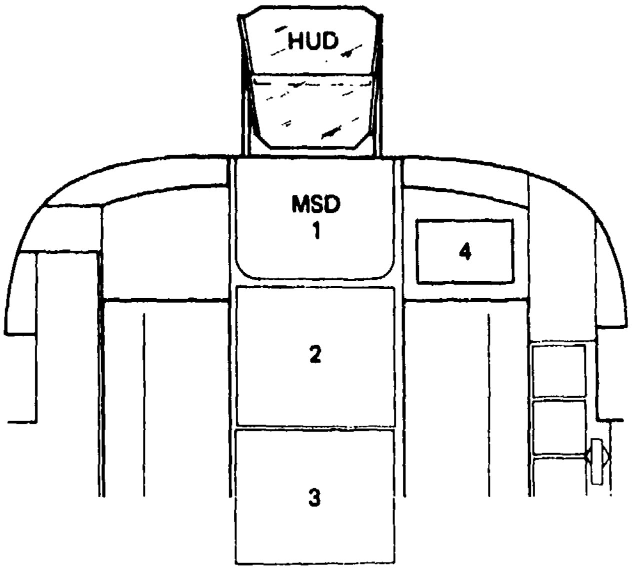

Display	Display Modes
HUD	A/A Attack - Steering and Cues A/G Attack - Steering and Cues NAV - Steering and Cues
MSD-1	RDR - A/A Search, A/A Attack, Ground Map and A/C Ranging TEWS - Exclusively EO - A/A and A/G Under the Nose Visual Aid ADI - Primary Reclined ADI
MSD-2	RDR - A/A Search, A/A Attack, Ground Map and A/C Ranging EO - A/A and A/G Visual Aid
MSD-3	EO - A/A and A/G Visual Aid HSD - Moving Map Display with TEWS Overlay
MSD-4	TEWS - Exclusively

Reclined

Upright

FIGURE 32
CONFIGURATION II DISPLAY FUNCTIONS

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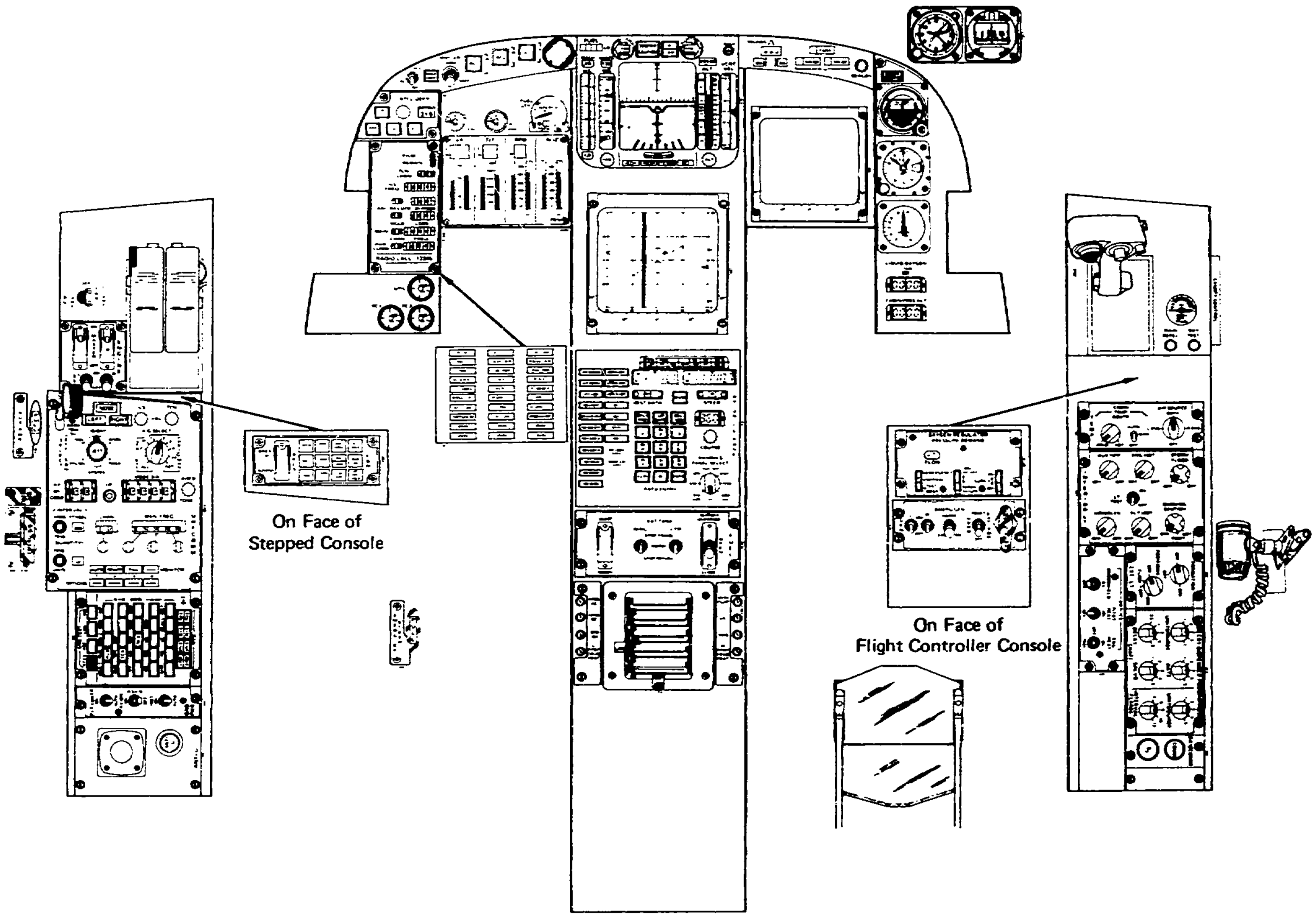

FIGURE 33
CONSOLE/INSTRUMENT PANEL MOUNTED CONTROLLER CONFIGURATION
Used with Controller Configuration D and E
Configuration III

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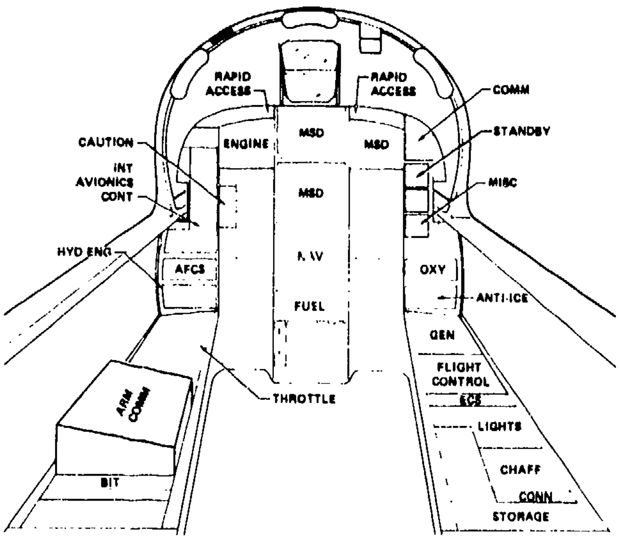
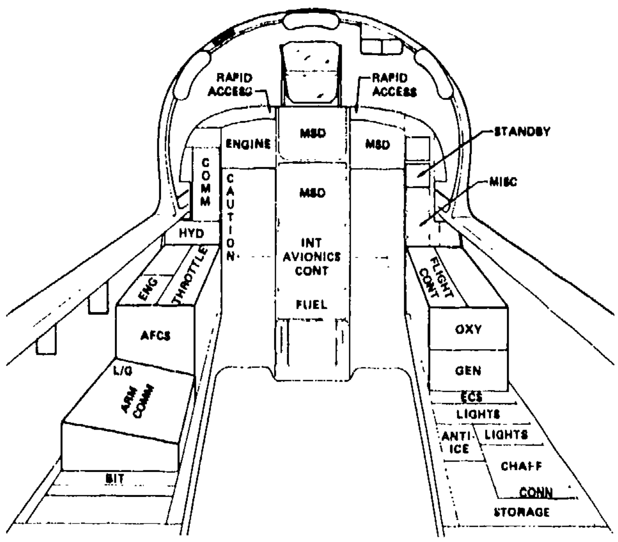
TABLE 8
CONTROL/DISPLAY DIFFERENCES

ITEM	LOCATION CONFIGURATION I	LOCATION CONFIGURATION III	JUSTIFICATION FOR CHANGE
Auxiliary Power	Rear face of armament panel	Under left sill	Improved access
Landing Gear Control	Left instrument panel	Armament panel	Throttle would interfere with control on instrument panel
Engine Control Panel	Lower left instrument panel	Top of throttle stepped console	Changes due to design of throttle mounting envelope which occludes portion of left console and instrument panel
FBW Panel	Lower left instrument panel	Face of throttle stepped console	
Hydraulic Gages	Lower left instrument panel	Mid left instrument panel	
Avionics Panel	Upper left instrument panel	Center console	
Landing Lights Switch	Mid left instrument panel	Top of throttle stepped console	
Comm Status Display	Top of right instrument panel	Top of left instrument panel	Relocation of avionics panel
Nav Display & Nav Entry	Center console	Integrated into avionics panel	Conserve panel space
Standby Flight Instruments	Mid right instrument panel	Top right instrument panel	Relocation of comm status, improved visibility
Emergency Vent	Mid right instrument panel	Face of flight controller console	Changes due to design of Flight Controller Mounting Envelope which occludes portion of right console and instrument panel
O_2 Panel	Lower right instrument panel	Face of flight controller console	
Anti Ice Panel	Lower right instrument panel	Right console	
Rain Repel & O_2 Test	Mid right instrument panel	Top of flight controller console	
LO_2 Quantity and Cabin Pressure	Mid right instrument panel right edge	Mid right instrument panel left edge	
Emergency Gen Panel	Left console	Face of flight controller console	



CONFIGURATION I
Used With Controller Configuration A



CONFIGURATION III
Used With Controller Configurations D&E

The integrated avionics panel which was relocated from the left instrument panel was redesigned to better utilize the available space on the center console. This original and redesigned versions are shown in Figure 34. Primary differences for Configuration III are: 1) side by side location of the data entry keys and function selectors, 2) use of a larger data display, and 3) incorporation of NAV controls and displays.

Configuration I

Configuration III

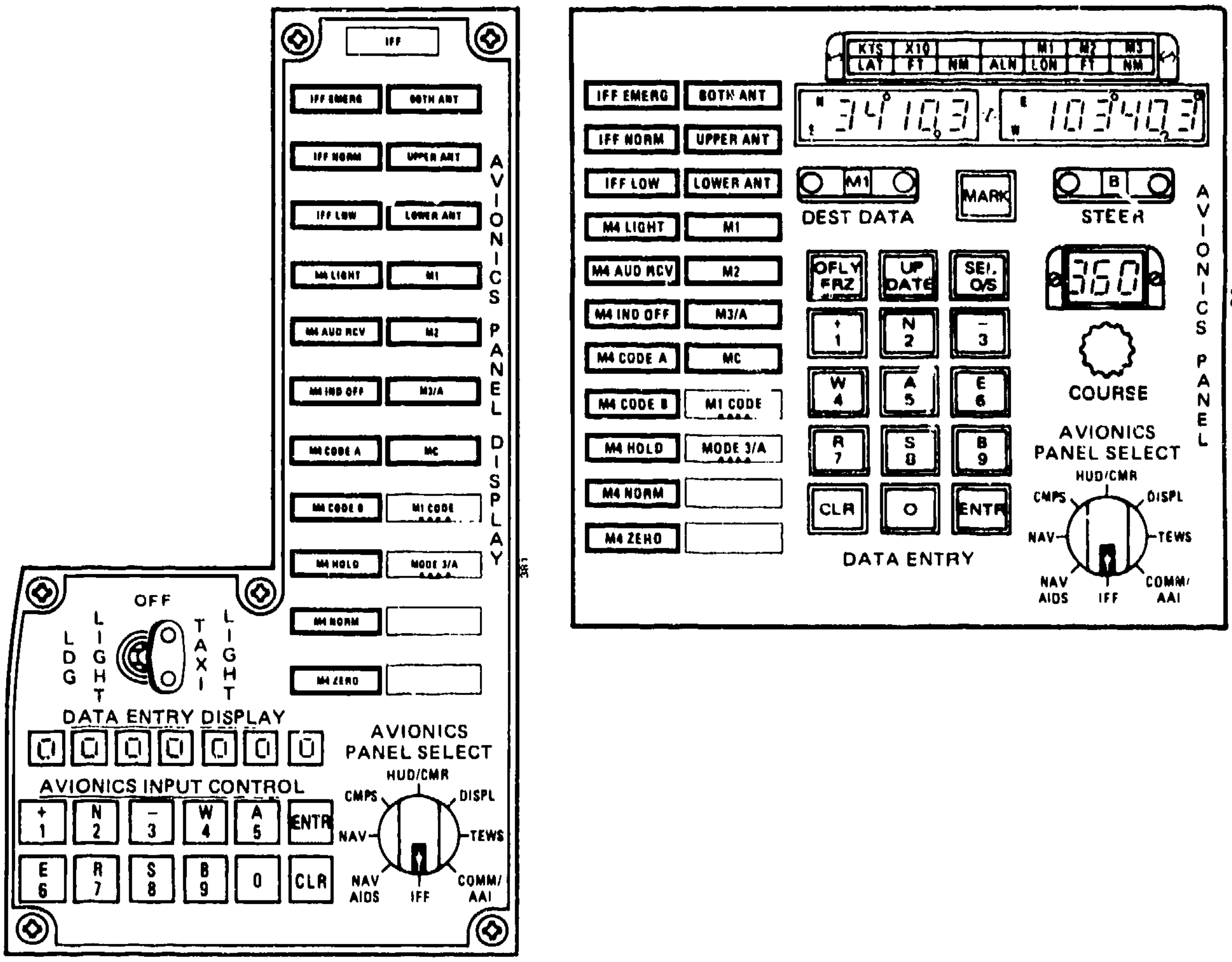


FIGURE 34
INTEGRATED AVIONICS PANEL

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SECTION V

CONCEPT EVALUATION

Alternative controller design concepts were evaluated by USAF pilots in a mission task environment, using the cockpit design aid illustrated in Figure 4. This evaluation was performed using a "static simulation" technique, enabling the pilots to attain a high degree of familiarity with the cockpit provisions. Functional tasks were defined compatible with a typical fighter mission profile. Pilot tasks subsequently were performed in a mission sequence during the evaluation phase. This enabled the evaluators to judge the utility of the controller locations and their integration according to definition of primary and secondary control/display needs for extreme seat positions. Their judgement was based upon a thorough indoctrination on the use of this cockpit in a mission context. Pilot personal equipment was worn to determine pilot/cockpit physical interfaces.

Task performance times were recorded for accomplishment of a set of specific tasks exploring all equipment design locations within the cockpit. Reach and vision envelopes were also measured for each pilot in each test configuration. This was coupled with the pilots' personal data (anthropometric measures and experience background) to relate their subjective preferences with objective measures.

EVALUATION APPROACH

The test criteria, Volume II of this report, considered evaluation of control/display and controller location options, including: seat location, motion, and pilot anthropometry; influence of design envelope and geometric factors on external vision; additional control complexity/congestion related to incorporation of direct lift and direct side force control; and a balance between the physical (static measurements, motions, and interactions) and operational (task performance and response) test measures and objectives using Air Force pilot subjects.

The primary test objectives considered both subjective and objective evaluation techniques. Briefly, these objectives were:

- o Evaluate physical and performance aspects of the controller location options
- o Provide a measure of pilot acceptance based on fulfillment of mission functional task objectives using the controller configuration options
- o Provide an assessment of controller location influence on anthropometric design (design influence for accommodation of 5th through 95th percentile pilots)
- o Determine indices of pilot workload for the configuration alternatives using an objective pilot simulation model
- o Provide a tangible basis for establishment of Research and Development goals leading to development of an operational high acceleration cockpit.

All of the above objectives were satisfied by using the engineering design aid described in Reference (4) as the baseline design aid and modifying this design aid for evaluation of the alternative concepts.

All test configurations emphasized controller/cockpit/seat integration with preservation of ejection clearances. All test configurations were equipped with a lap belt and shoulder harness to restrain the pilot. A canopy was also included which, together with the pilot adjusted restraint system, insured realistic evaluation of the test configurations. Primary emphasis was placed on internal (display) and external visual capability, control location and utility, anthropometry and ejection capability. The primary control and display philosophy was to provide optimum head-up operation during close-in combat. The evaluation phase included an examination of four controller mechanization concepts for potential use in a high acceleration fighter design.

FIGHTER MISSION EVALUATION PROFILE

A mission profile was defined in Reference (4) for determination and evaluation of pilot functional tasks pertinent to a high acceleration cockpit design. The mission profile, illustrated in Figure 35, provides a representative sampling of the major operational functions anticipated.

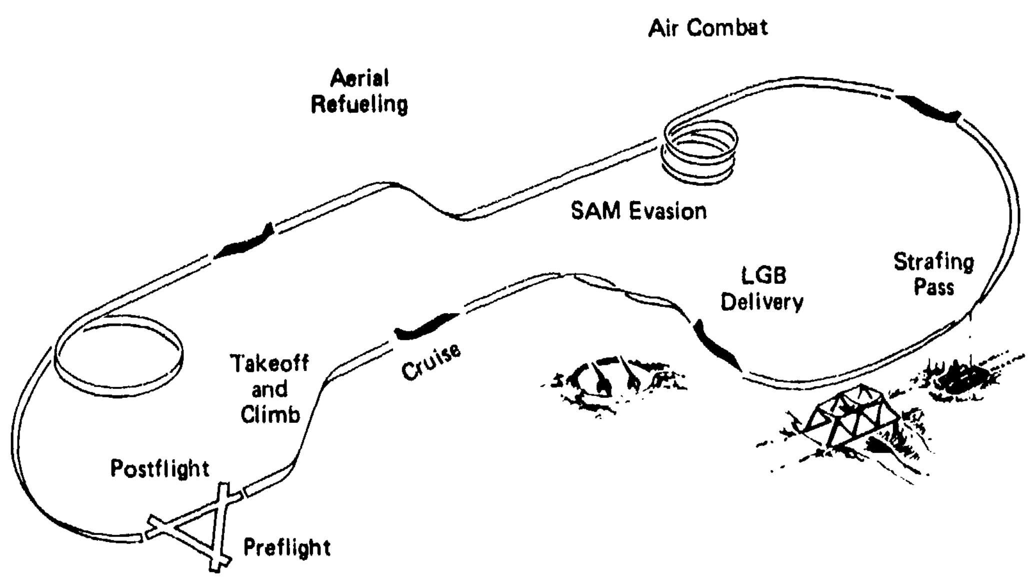

FIGURE 35
FIGHTER MISSION EVALUATION

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The normal flight phases include pre-flight and post-flight checklists, cruise set-up and an aerial refueling task. It is anticipated that the seat would be placed in an upright position during normal flight phases. However, a partially reclined seat provides a desirable option from a pilot comfort standpoint; and most tasks could be satisfactorily accomplished from a partially reclined position.

The combat phase is initiated with a jinking maneuver at mid-to-low altitudes to minimize AAA attrition and provide sufficient response time for SAM evasion. SAM evasive maneuvers are exercised as both the lead fighter and his wing man press toward a primary target. Cooperative designation and weapon delivery are performed using a laser guided bomb against a bridge from a moderate-to-steep dive with maximum use of load factor to reduce slant range and residence time within enemy weapon range. Air-to-Ground mission tasks are completed with both aircraft operating as a unit, in a shallow dive strafing pass at a target of opportunity. The final phase of the combat profile is an aerial engagement at Mach .9 and 10,000 ft on the return.

The four controller configurations, discussed in Section III, were the principal independent test variables. A full list of the independent test variables associated with these configurations is presented in Volume II.

SECTION VI

TEST RESULTS

For purposes of test structuring and subsequent data collection, reduction, and reporting, dependent test variables were categorized according to subjective or objective measures.

Results of the objective test sessions reinforce the pilot subjective preferences for the console mounted controller configuration which elevates in a vertical plane as the seat articulates. Highlights of the dependent test variables are summarized in this section. A full set of reduced data is presented in the appendices of this report.

OBJECTIVE TEST RESULTS

The objective test sessions were:

a) Background questionnaire used to determine pilot experience (hours)

b) Peripheral vision envelopes of each pilot determining individual differences in vision envelopes (horizontal and vertical degrees)

c) Anthropometric measurements yielding relative pilot size (age, weight, inches)

d) Physical reach and interference in each of the four test configurations (inches)

e) Task performance evaluation of the control/display and controller configurations (time, seconds)

f) Eye and head movement yielding visual patterns for design and configurations (degrees).

In general, results of these objective sessions support the subjective preference for Configuration E. The anthropometric measurements correlate with the pilot's ability to perform specified tasks in the reclined (65°) position. Visual interference envelope measures favor Configurations A and E, and the dynamic eye/head movement data support Configurations A and B. The following presentation discusses each test session, trends, and data.

Pilot Background Questionnaire

A pilot background questionnaire was used to determine pilot experience in aircraft, combat, and exposure to high load factor maneuvers. The range of test subject experience is illustrated in Table 9. These data lend credence for generalizing the test data to the pilot population. The four subjects were provided by the Air Force and all met the requested requirements of:

- o Jet pilots, current flight status in fighter type aircraft

- Air combat experience
- Air-to-ground weapons delivery experience
- High load factor experience.

These four pilots had flight experience covering seven different aircraft types. F-4 flight experience accounted for 4,970 of the 7,627 total flight hours.

TABLE 9
PILOT BACKGROUND

QUESTION	PILOT RESPONSE
Aircraft Current In (Listed in Descending Flight Hours)	F-4E, T-38, F-106, T-33
Other Aircraft Experience (Listed in Descending Flight Hours)	F-4B, F-4C, F-4D, T-37, F-4B, F-4J, F-101, F-102
Total Flight Hours	612-2600 Hours (Average 1906 Hours)
Air-to-Air Combat	4 Pilots - Air Combat Maneuver (ACM) Practice
Air-to-Ground Weapon Delivery	3 Pilots in Southeast Asia (SEA)
Load Factor (G) Experience	4 Pilots, 5-7G, 15-40 seconds (ACM) 1 Pilot, 8.5G, 40 seconds (Centrifuge) 1 Pilot, 9.0G, 2-3 seconds
Rank	3 Captains 1 Major
Ejection Experience	1 Pilot from F-101

The background questionnaire also included a high G need/requirement question. The general opinion of all four pilots on the necessity of G tolerance improvement was:

a) "Yes, G tolerance improvement is necessary. The main reason is to enable the pilot to obtain the maximum performance from the latest type aircraft being built and foreseen to be capable of sustaining greater than 7Gs. In this environment, the pilot is the weakest link, and his physical capacity for sustaining high G loads must be improved to obtain maximum performance from both man and machine."

b) "Yes, today's aircraft design has gotten to the point where the aircraft is capable of greater performance than the pilot. Aircraft control in a high acceleration environment will enable expansion of today's air-to-air

tactics. High acceleration cockpit will reduce pilot fatigue and provide better pilot vision and awareness at higher G loads."

c) "Yes, development of fighters with high G performance demands a high acceleration cockpit."

d) "Yes, based upon development of fighters that can sustain high G turn rates. It is a physiological fact that higher G tolerances are going to be necessary. A high acceleration cockpit will help gain an offensive position and also be useful in negating an opponent's attack when on the defense."

In general, these subjects had a broad range of experience and are an excellent/representative test sample.

Visual Envelope

Peripheral vision envelope was measured for each of the four pilot subjects. The measurements were taken with the use of an American Optical Screening Perimeter, shown in Volume II, for two cases: (1) pilot subject wearing his flight helmet and oxygen mask, and (2) pilot subject without flight helmet and mask. Measurements were made with the perimeter at eight different settings (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) in the vertical plane, fixed head, looking forward, for both the left and right eyes. Targets were presented using the sequential method of limits with counterbalanced starting positions. Peripheral vision measurements, in conical degrees with the center focus at 0°, were then recorded.

The data for the four pilot subjects are depicted in Table 10. The average value and standard deviation for each of the eight settings were computed. These average values can be illustrated by a plot, such as presented in Reference (6). It is readily apparent from this type of figure that wearing the flight helmet and oxygen mask degrades the subject's unhindered peripheral vision by approximately 25%, mainly in the lower quarter of the peripheral vision field of view.

Anthropometric Measures

Anthropometric measurements were taken for each pilot. These measurements were made in order to learn relative pilot size for such dimensions as sitting eye height and reach distance. By knowing each pilot's relative size, his responses and capabilities in succeeding test sessions became even more meaningful to the evaluators. Measurements were made with each pilot wearing his flight suit both with and without his flight helmet. Measurements for the 0° back angle were made with the pilot either standing or sitting in an erect manner. Standard anthropometric measuring tools were used to take all measurements. Corresponding percentiles of these measures are shown in Table 11 (percentiles are based on 1967 Survey of USAF Flying Personnel).

In general, the four pilots comprised an excellent sample with which to evaluate a crew station designed to accommodate the 5th through 95th percentile pilot population. This sample contained small, large, light and heavy

TABLE 10
PERIPHERAL VISION ENVELOPE
Degrees

Without Helmet and Mask

INSTRUMENT SETTING		LEFT EYE					RIGHT EYE				
		90°	135°	180°	225°	270°	0°	45°	90°	270°	315°
PILOT	1	50	60	110	90	80	110	65	50	75	85
	2	50	65	110	70	70	110	70	50	70	90
	3	55	70	110	80	55	110	60	50	70	85
	4	50	70	110	70	65	110	65	55	70	85
	M	53.8	66.3	110.0	77.5	67.5	110.0	65.0	51.3	70.1	86.1
	S	7.50	4.78	0.0	8.29	9.01	0.00	3.54	2.50	2.50	2.5

With Helmet and Mask

INSTRUMENT SETTING		LEFT EYE					RIGHT EYE				
		90°	135°	180°	225°	270°	0°	45°	90°	270°	315°
PILOT	1	50	70	110	80	50	110	67.5	55	50	85
	2	45	60	110	65	40	110	60	45	35	65
	3	40	50	110	60	32.5	110	65	40	32.5	40
	4	50	60	110	70	40	110	60	55	45	70
	M	46.3	60.0	110.0	68.8	40.6	110.0	63.1	48.8	40.6	65.0
	S	4.79	8.16	0.00	8.54	7.18	0.00	3.75	7.50	8.26	18.71

M - the sample mean
S - standard deviation computed for sample data

pilots. Several measures came very close to providing the desired 5th through 95th percentile measurements.

Selected measurements were also taken at back angles of 20° and 65°; the average measurements of the four pilots are depicted in Table 12. No percentile scores are given because there is no standard percentile ranking for measures at back angles other than the standard 0° back angle. Obviously, the values of eye height, shoulder height, and sitting height are influenced by the seat back angle, as previously reported in Reference (6). The measures are not a direct cosine function of the 0° back angle measures, highlighting the need for additional anthropometric work to provide future cockpit design guidelines. Previous seat design and crew station integration analyses have assumed this cosine function.

TABLE 11
PILOT ANTHROPOMETRIC PERCENTILE

MEASURE	1	2	3	4	M*	M**	S***
Weight	82	11	80	9	45	159.4	26.6
Stature	89	46	85	5	55	176.4	8.2
Eye Height	86	20	92	8	55	165.1	8.9
Sitting Height	64	55	10	1	10	87.2	6.8
Eye Height (Sitting)	13	7	10	1	3	73.8	4.7
Shoulder Height (Sitting)	60	56	45	1	17	56.3	3.8
Thigh Clearance	1	7	3	3	4	12.1	0.5
Knee Height	95	18	77	35	65	56.1	2.9
Buttock - Knee Length	22	9	80	3	22	57.9	3.2
Buttock - Leg Length	84	25	57	15	45	107.7	4.5
Shoulder Elbow Length	80	1	93	43	48	36.3	2.9
Maximum Reach From Wall	30	80	10	1	23	94.5	5.6
Functional Reach From Wall	48	85	18	14	40	81.0	3.9
Elbow - Elbow Breadth	97	96	99	80	96	50.8	2.8
Hip Breadth	99	40	86	7	63	36.2	3.3
Shoulder Breadth	95	55	99	35	85	47.8	3.3
Hand Length	75	57	10	1	27	18.5	1.1
Palm Length	63	57	1	13	13	10.1	0.6
Hand Breadth At Thumb	90	10	97	15	57	10.4	0.8

* Mean Sample percentile of the average measurement of 4 pilots.
** Mean (Units are lbs for weight and centimeters for the other).
***Standard Deviation (Units are lbs for weight and centimeters for the other)

TABLE 12
PILOT MEASUREMENTS
Centimeters

MEASURE	SEAT BACK ANGLE					
	0°		20°		65°	
	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION
EYE HEIGHT	74.8	4.72	71.7	4.50	55.3	3.79
SHOULDER HEIGHT	56.4	3.83	53.6	3.21	38.9	3.07
SITTING HEIGHT	89.2	6.75	85.7	4.79	69.[illegible]	9.49

Physical Reach, Visual Interference Envelopes

Measurements of each pilot's physical reach and interference envelopes were taken with the pilot in the crew station design aid for each of the four test configurations. In this manner the crew station design aid in general, and configurations in particular, were evaluated in terms of a pilot's ability to reach the necessary controls with a minimum of interference from controller or seat placement.

Physical Reach and Interference Envelope - The pilot was seated in the design aid with the canopy in place and was restrained in the seat by the lap belt and an unlocked shoulder harness; which is the common flight procedure. He was asked to reach different controls in different sequences from both the upright and reclined seat positions. Each of the four test configurations was presented, and the pilot was asked to reach and operate controls such as master caution, master arm, fly-by-wire control panel, and ejection handles. The design aid canopy was a grid configuration. Whenever the pilot's head exceeded the geometrical limitations of the design envelope, the helmet was restrained by the test conductor to insure that valid reach envelopes were obtained.

Data was recorded in terms of pilot ability or inability to reach the controls. Reasons for failure to reach or operate a control are:

- Too far away
- Interference from throttles or flight controller
- Reclined 65° seat position blocks part of the center console.

Reach data is tabulated for each configuration in Table 13. The effect of each configuration on pilot operating capability is also noted. These results favor Configurations D and E with decreasing capability for B and A.

Visual Interference Envelope - Data were also recorded in terms of pilot ability or inability to view the control/display panels. The pilot was restrained in the seat by the lap belt and shoulder harness. He was asked not to move his head. Data are summarized by the area plots in Figures 36 through 38; representing the minimum area capability of the four pilots. If pilots were allowed to move their heads and arms, the visual ability was 100% except for the area blocked by the articulating seat at 65° back angle. If a survival vest were worn, the visual interference for all configurations would increase to account for the added bulk on the pilot's chest. As the survival kit is a highly variable item, depending on the theater of operation, it was impracticable to include it in this evaluation. Configuration A incurred the lowest visual interference followed by Configuration E, D, and B in increasing order.

Task Performance Measures

Task performance times were collected on 33 tasks for the purpose of effecting a comparative evaluation of the controller-throttle locations and

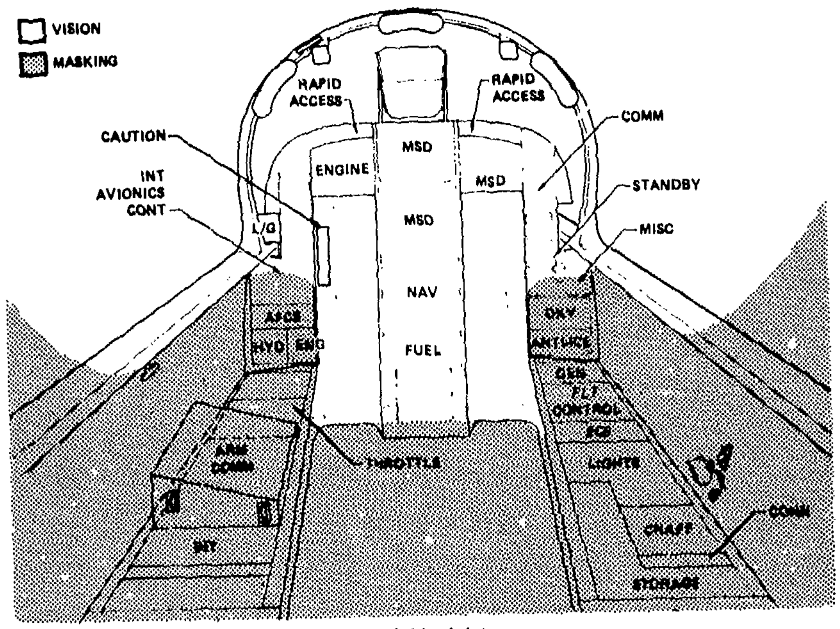
TABLE 13
PHYSICAL REACH AND INTERFERENCE
65° Seat Back Angle*

CONFIGURATIONS	PERCENT OF COCKPIT AREA REACHABLE (%)	CONTROLS NOT REACHABLE
A (FIXED CONSOLE MOUNTED)	78	AFCS, HYD, ENGINE, OXYGEN, ANTI-ICE, GENERATORS, NAV, FUEL, AIR VENT, CIRCUIT BREAKERS
B (OVER-THE-LAP SEAT MOUNTED)	86	HYD, ENG, FUEL, GENERATOR, ANTI-ICE, AIR VENT, CIRCUIT BREAKER
D (INSTRUMENT PANEL MOUNTED WITH VERTICAL ADJUST)	89	LANDING/TAXI LIGHT, INTEGRATED AVIONICS CONTROL, NAV, FUEL, AIR VENT, CIRCUIT BREAKER
E (CONSOLE MOUNTED - VERTICAL TRAVEL-LONGITUDINAL)	89	LANDING/TAXI LIGHT, INTEGRATED AVIONICS CONTROL, NAV, FUEL, AIR VENT, CIRCUIT BREAKER

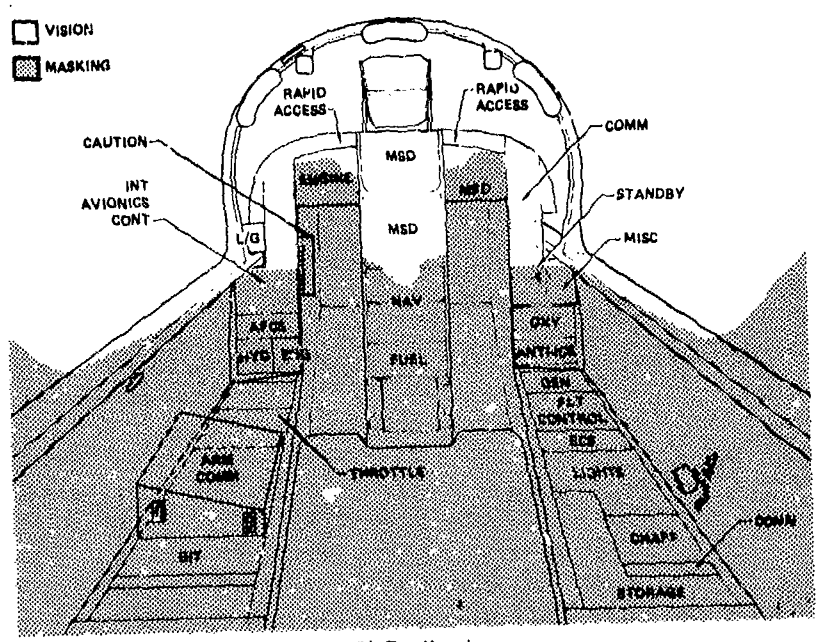
*All configurations are 100% reachable at the 20° seat back angle.

the overall cockpit geometry associated with each location. A stratified sampling technique was applied to select tasks that would provide an assessment of reach adequacy to the left console, right console, and main instrument panel.

The pilot was seated in the crew station design aid with the canopy in place. He wore his flight suit, flight helmet, oxygen mask, anti-G suit, and gloves, and was restrained in the seat by the lap belt and shoulder harness. The test conductor called out each task to be performed. With his hands at a neutral starting point (on the throttle or flight controller), the pilot, when given a light signal, performed each task at a normal pace. He then returned his hand to the neutral position. His response time (from neutral position to neutral position) was measured. Each of the four pilots was administered all the configurations involved in the experiment. The order in which the configurations was administered was independently randomized for each of the pilots. This minimized systematic carryover effects from one configuration to the next. The statistical techniques, applied to investigate the difference between the various configuration means, utilized a three-way analysis of variance, one correlated sample Student's t test, and multiple range tests of comparison of means.



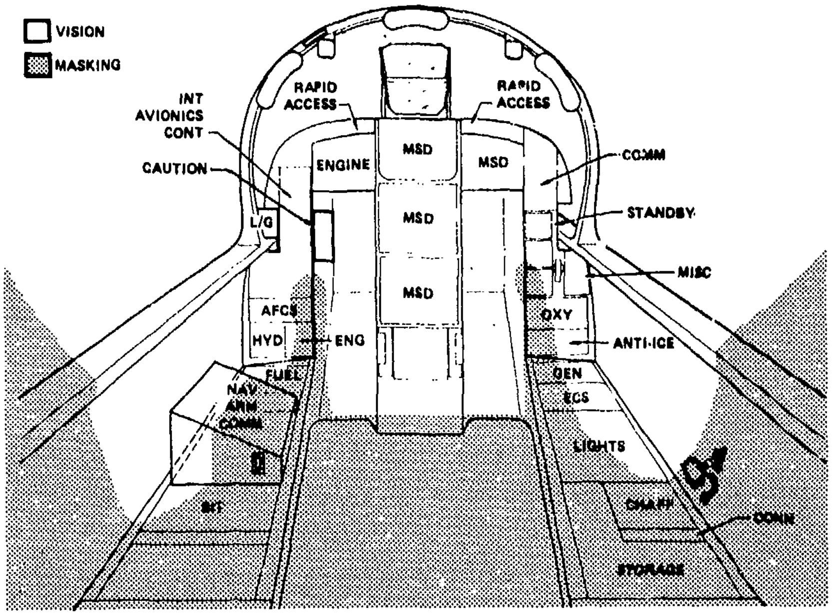
A) Upright



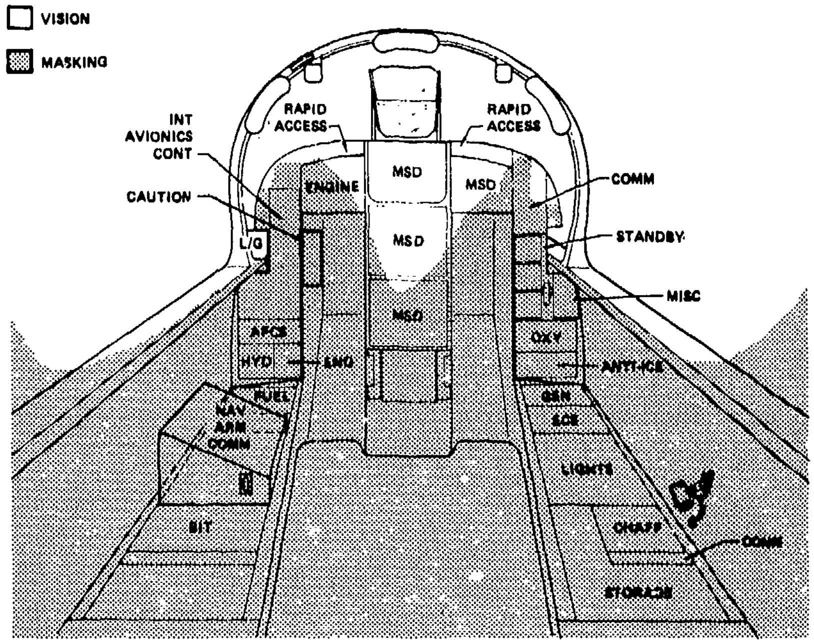
B) Reclined

FIGURE 36
CONFIGURATION A VISION ENVELOPE
No Head Motion

GP73-1085-2

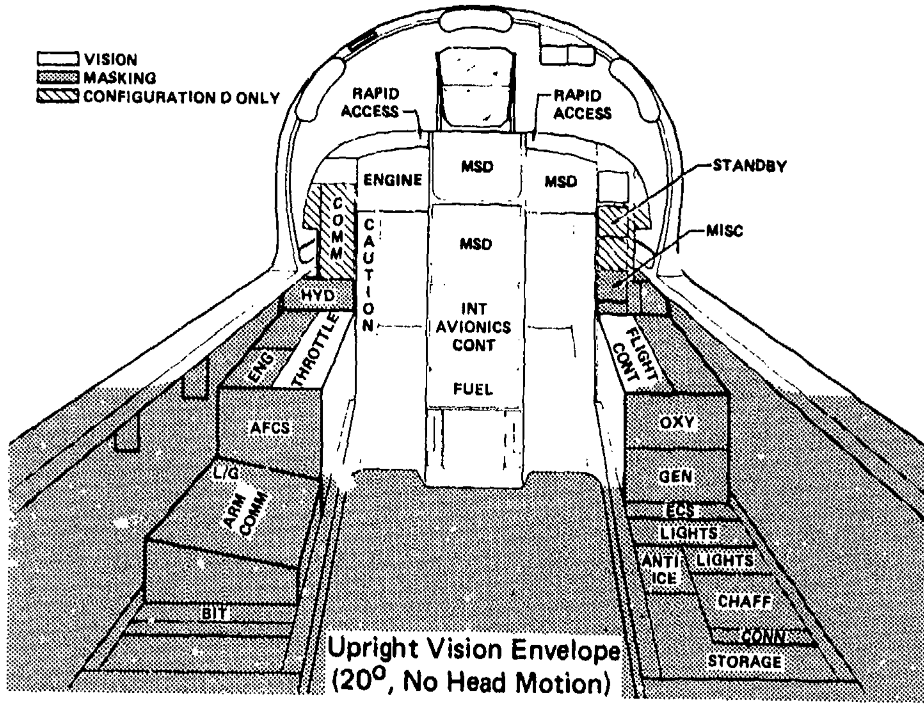


A) Upright



B) Reclined

FIGURE 37
CONFIGURATION B VISION ENVELOPE
No Head Motion



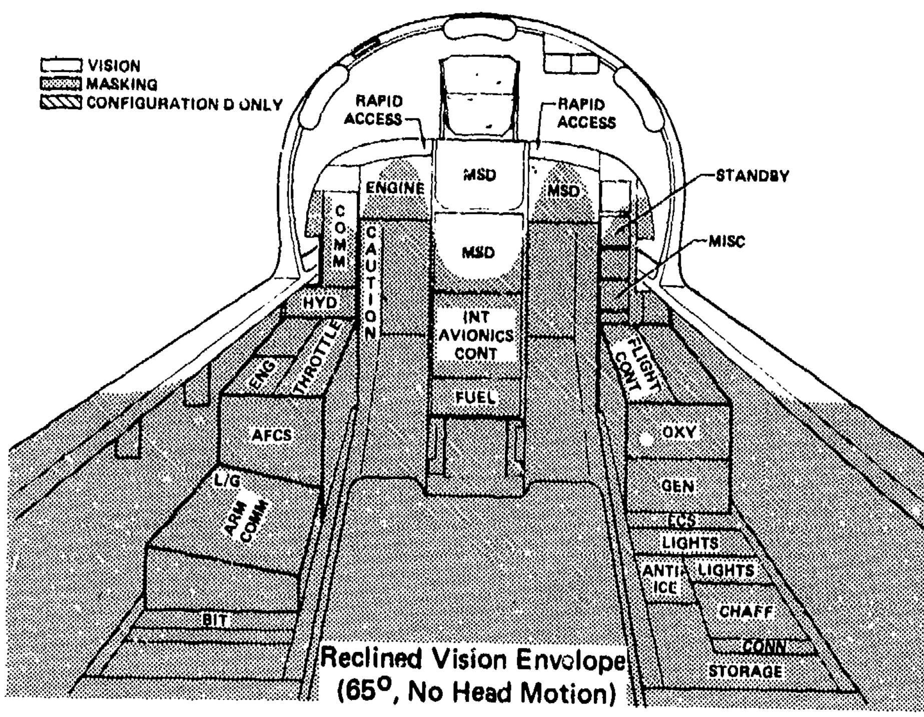


FIGURE 38
CONFIGURATIONS D AND E
VISION ENVELOPE

GP74-0757-62

Eleven of the 33 tasks noted in Table 14, were not performed in all configurations in the 65° position. These eleven tasks were in areas blocked by the reclined seat (lower portion of the center console) or beyond pilot reach. Only the data for the remaining 22 tasks was analyzed as a 4x8x22 analysis of variance to obtain a ranking of the controller locations in terms of task performance times. It should be noted that tasks 23 through 33 are not combat functions and do not degrade the utility of the crewstation in a high threat environment.

TABLE 14
TASKS

TASK NO.	TASK DESCRIPTION
1	GROUND POWER AVIONICS ON
2	EMERGENCY SPEED BRAKE
3	AUXILIARY POWER
4	TACAN BIT
5	UHF COMMUNICATION CHANNEL
6	UHF COMMUNICATION CHANNEL/ FREQUENCY
7	SELECT JETTISON COMBAT/STORES
8	LANDING LIGHTS
9	LANDING GEAR
10	LANDING LIGHTS/LANDING GEAR/PUSH TO JETTISON
11	JAMMER PUSH BUTTON
12	PUSH TO JETTISON
13	MASTER ARM
14	"VI" MASTER MODE
15	MASTER CAUTION
16	"MSD 1" RADAR MODE
17	EMERGENCY VENTILATION
18	TEMPERATURE PANEL AIR SOURCE OFF TO BOTH
19	INTERIOR LIGHTS OFF TO BRIGHT
20	EXTERIOR LIGHTS OFF TO DIM
21	DECOY CHAFF UNITS/BURST 3 TO C
22	DECOY FLARES INTERVAL 8 TO 12

TASK NO.	TASK DESCRIPTION
23	FBW AFCS MASTER
24	AVIONICS PANEL IFF TO HUD/CMR
25	AVIONICS INPUT "E" KEY
26	"E"/CLEAR/ENTER KEYS AVIONICS INPUT
27	IFF EMERGENCY PUSH BUTTON AVIONICS PANEL
28	M4 ZERO
29	IFF/EMERGENCY/M4
30	NAVIGATION DISPLAY MARK
31	FUEL PANEL SLIPWAY OVERRIDE ON
32	ANTI-ICE PITOT HEAT ON
33	EMERGENCY ON

An additional variance test was performed for Configuration E. The observation data for E65 with arm rest was compared to that for E65 without arm rest using a correlated sample Student's t test. Duncan's Multiple Range test was used, whenever appropriate, to isolate pairs of mean values which were significantly different. An alpha of 0.05 was set for all tests of significance; where the computed statistics satisfied the 0.01 level, this information was noted. An explanation of the computer programs and the statistical tests used are provided in References (7) through (10).

Task Performance - The results of the analysis of variance (ANOVA) are summarized in Table 15. All main and interaction effects were significant at the 0.01 level. The main effect (P) represented a comparison of means among the four pilots averaged over 8 configurations and 22 tasks. The pilot mean task performance times over all configurations are depicted in Table 16. The fact that all two-factor interaction effects are significant indicates that the differences among the pilots were dependent upon specific configurations and specific tasks. Likewise, the main effect (C) is a comparison of means among the eight configurations, four controller locations at two seat back angles each, averaged over four pilots and 22 tasks. The main effect (T) is a comparison of means among the 22 tasks averaged over eight configurations and four pilots. These all are to be interpreted in an identical manner, i.e., any significant differences among the configurations must be qualified by identification of specific pilots and specific tasks. Similarly, tasks will reveal differences relative to the specific configurations and pilots involved. The three-factor interdependence is the result expected since, logically, anthropometric as well as other organismic variables would affect the pilots' responses to a particular configuration. As for the tasks themselves, both the configuration context in which they were presented as well as the design and location of the control or display itself would have yielded differences using performance time as a criterion measure. Since differences in the configurations formed the primary test structure, the differences

TABLE 15
TASK PERFORMANCE ANOVA

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F
Pilots (P)	3	89.223	29.741	90.90*
Configurations (C)	7	118.082	16.869	9.35*
Tasks (T)	21	550.346	26.207	26.63*
Pilots x Configurations	21	37.889	1.804	5.51*
Pilots x Tasks	63	62.001	0.984	3.01*
Configurations x Tasks	147	106.786	0.726	2.22*
Residual	441	144.281	0.327	
Total	703	1108.606		

*Significant (P<.01)

TABLE 16
PILOT TASK PERFORMANCE
Time to Perform Tasks (Seconds)
176 Observations

PILOTS	MEANS (M)	STANDARD DEVIATION (SD)
1	3.18	
2	2.89	
3	2.60	0.852
4	3.50	

among the eight configuration means were systematically paired and tested using Duncan's Multiple Range test, Reference (10). The results, depicted in Table 17, indicated that: (1) Performance times at 20° seat angle were generally shorter than at 65° seat angle, irrespective of configurations. The 20° seat angle test time means ranged from 2.43 to 2.90 seconds; Configuration B was low and D was high. The difference between the two was significant. The difference between all other pairs was not statistically different; (2) The means for 65° seat angle ranged from 3.15 to 3.62 seconds. Configuration A was low and B was high. The difference between the two was significant. The difference between all other pairs was not statistically significant; (3) While the data failed to yield significant differences at a given seat angle (20° or 65°), the mean times between seat back angles were significantly different. At 65° Configuration B produced greater performance times than all other configurations followed by Configurations E, D, and A in descending order.

TABLE 17
TASK PERFORMANCE
Duncan's Multiple Range Test
n = 88 Observations per Configuration

Config.		(1) B20	(2) E20	(3) A20	(4) D20	(5) A65	(6) D65	(7) E65	(8) B65	Shortest Significant Range	
	Mean	2.43	2.69	2.74	2.90	3.15	3.42	3.54	3.62	.05**	.01*
(1)	2.43	-	0.26	0.31	0.47**	0.72*	0.99*	1.11*	1.19*	R_2=0.396	0.521
(2)	2.69		-	0.05	0.21	0.46**	0.73*	0.85*	0.93*	R_3=0.417	0.543
(3)	2.74			-	0.16	0.41	0.68*	0.80*	0.88*	R_4=0.431	0.558
(4)	2.90				-	0.25	0.52**	0.52**	0.72*	R_5=0.442	0.569
(5)	3.15					-	0.27	0.39	0.47**	R_6=0.450	0.578
(6)	3.42						-	0.12	0.20	R_7=0.457	0.585
(7)	3.54							-	0.08	R_8=0.462	0.591

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

When the 20° and 65° observations were combined, the results, as summarized in Table 18, indicated no significant difference. The range was 2.95 to 3.16 seconds, with Configuration A on the low end and Configuration D on the high end of the range.

TABLE 18
COMPARISON OF TASK PERFORMANCE MEANS
Duncan's Multiple Range Test
n = 176 Observations per Configuration

Config.		(1) CONF.A	(2) CONF.B	(3) CONF.E	(4) CONF.D	SHORTEST SIGNIFICANT RANGE	
	Mean	2.95	3.03	3.12	3.16	.05**	.01*
(1)	2.95	-	0.08	0.17	0.21	R_2=0.562	R_2=0.737
(2)	3.03		-	0.09	0.13	R_3=0.590	R_3=0.768
(3)	3.12			-	0.04	R_4=0.610	R_4=0.788
(4)	3.16						

(1) (2) (3) (4)

*SIGNIFICANT (P<.05)
**SIGNIFICANT (P<.01)

Means not underscored by the same line are significantly different.

Task differences were analyzed in order to provide additional information for deriving some final weighted selection of a specific configuration. Table 19 lists the 22 tasks used in the analysis previously discussed. The means and standard deviations are based upon n=4 observations for each task. The standard error of the mean represents the standard deviation of the sampling distribution of means for a specific task averaged across the eight configurations. Tasks coded with one or two asterisks indicate significant differences. Separate Duncan's multiple range tests were performed on these tasks and are included as Tables 40 through 55 in Appendix A.

It appears that controls and displays for other tasks in the immediate location of those specifically manipulated in the tasks tested would probably produce approximately the same mean values (if the design of the controls and displays were similar). Consequently, it is possible to estimate the number of controls and displays that would be affected by increased task times due to interference of the throttle and flight controllers.

The net result of the findings in Appendix A indicates that Configuration B at 65° seat angle showed increased task time for more pairs tested than other configurations. Configurations D and E were about the same while A was the lowest.

Task Performance-Arm Rest - The last analysis was to compare E65 with and without arm rests. This was done for the 22 tasks listed in Table 19. A correlated sample Student's t test, Reference (8), was used. The computed t

TABLE 19
TASK PERFORMANCE
Seconds

TASK NO.	TASK DESCRIPTION	CODE	A20		A65		B20		B65		D20		D65		E20		E65		STD ERROR OF MEAN
			MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	
1	GROUND POWER AVIONICS ON	NS	3.28	0.62	3.55	0.90	2.68	0.38	3.35	0.84	2.70	0.50	3.60	0.61	2.73	0.17	3.58	0.51	.28
2	EMERGENCY SPEED BRAKE	**	2.15	0.17	2.90	0.46	2.28	0.42	2.78	0.36	2.35	0.25	2.48	0.39	2.30	0.28	2.80	0.57	.18
3	AUXILIARY POWER	*	2.53	0.21	3.43	0.56	2.05	0.50	2.60	0.64	2.38	0.36	3.33	0.85	2.43	0.29	2.75	0.81	.26
4	TACAN BIT	*	2.98	0.51	3.60	0.61	2.73	0.66	4.10	0.85	3.36	0.22	4.08	0.48	2.98	0.40	3.83	1.02	.30
5	UHF COMMUNICATION CHANNEL	**	3.20	1.44	2.88	0.70	2.40	0.67	3.68	0.90	2.63	0.43	3.88	0.59	2.43	0.25	3.25	0.81	.36
6	UHF COMMUNICATION CHANNEL/FREQUENCY	NS	4.15	1.01	5.18	1.41	3.88	1.09	4.85	1.48	4.33	0.69	4.70	0.67	3.78	0.75	5.15	1.69	.55
7	SELECT JETTISON COMBAT/STORES	NS	3.50	0.59	3.78	0.79	3.18	0.51	4.10	0.80	3.20	0.48	3.38	0.71	3.38	0.79	4.05	1.08	.36
8	LANDING LIGHTS	*	2.25	0.10	2.23	0.59	2.20	0.87	2.73	0.56	3.25	0.60	3.53	0.82	2.80	0.55	5.45	0.86	.26
9	LANDING GEAR	*	2.73	1.36	2.18	0.42	1.73	0.28	1.83	0.69	2.40	0.53	3.55	1.99	1.93	0.28	2.75	0.57	.38
10	LANDING LIGHTS/LANDING GEAR/PUSH TO JETTISON	*	3.40	0.68	4.08	0.65	3.40	1.08	4.68	0.54	4.78	0.51	4.55	0.59	4.33	1.13	6.00	1.72	.43
11	JAMMER PUSH BUTTON	**	1.93	0.19	2.20	0.48	1.73	0.39	2.48	0.26	2.25	0.33	2.33	0.46	2.03	0.56	2.20	0.49	.20
12	PUSH TO JETTISON	NS	1.83	0.25	1.95	0.19	1.80	0.08	2.23	0.40	1.85	0.21	1.93	0.17	1.85	0.41	1.95	0.26	.13
13	MASTER ARM	*	1.95	0.44	1.98	0.36	1.70	0.24	2.40	0.37	1.80	0.32	2.13	0.36	1.75	0.39	1.90	0.39	.16
14	"VI" MASTER MODE	NS	1.88	0.49	1.83	0.43	1.78	0.36	1.95	0.39	2.03	0.22	2.15	0.31	1.88	0.45	2.10	0.36	.18
15	MASTER CAUTION	NS	1.90	0.20	2.08	0.25	1.65	0.30	2.18	0.43	1.80	0.22	[illegible]	[illegible]	1.78	0.46	2.05	0.58	.17
16	"MSD 1" RADAR MODE	**	2.13	0.19	2.38	0.86	1.78	0.31	2.53	0.34	2.28	0.36	2.65	0.59	1.73	0.13	2.15	0.48	.26
17	EMERGENCY VENTILATION	*	2.25	0.19	2.15	0.40	2.00	0.34	3.03	0.79	2.40	0.54	3.08	0.68	2.18	0.41	3.23	0.73	.25
18	TEMPERATURE PANEL AIR SOURCE OFF TO BOTH	*	2.68	0.47	3.90	0.98	2.95	0.13	5.75	2.34	3.15	0.56	3.98	1.03	2.85	0.96	5.10	1.90	.52
19	INTERIOR LIGHTS OFF TO BRIGHT	**	3.45	0.78	4.45	1.42	2.88	1.26	5.95	2.35	3.78	0.95	4.60	1.83	3.45	0.76	5.58	2.22	.72
20	EXTERIOR LIGHTS OFF TO DIM	*	3.50	0.79	3.95	0.92	3.18	0.44	5.83	1.75	4.48	0.82	4.70	1.19	3.60	1.16	4.73	1.08	.51
21	DECOY CHAFF UNITS/BURST 3 TO C	*	2.80	0.46	4.13	0.72	2.73	0.33	5.23	1.53	3.18	0.39	4.03	0.80	3.35	0.69	4.68	0.83	.36
22	DECOY FLARES INTERVAL 8 TO 12	*	3.80	1.13	4.48	0.29	2.78	0.48	5.40	1.70	3.48	0.82	4.28	1.15	3.80	0.34	4.63	0.85	.42

CODES:
NS - NOT SIGNIFICANT
* - SIGNIFICANT (P<.01)
** - SIGNIFICANT (P<.05)

was 4.55, which was significant at the 0.01 level for a one-tailed test. Performance times for E65 with the arm rest were, on the average, 0.71 seconds higher than without the arm rest.

Eye and Head Motion Measures

The objective of this experiment was to compare the visual responses of the pilots to the four controller configurations at 20° and 65° seat back angles. The criterion measures were horizontal eye movement, horizontal head movement, total horizontal eye/head movement, vertical eye movement, vertical head movement, and total vertical eye/head movement.

The pilot was seated in the design aid. He wore his flight suit, flight helmet, oxygen mask, anti-G suit, and gloves and was restrained in the seat by the lap belt and shoulder harness. Eye movements were detected by an electrical method. EEG electrodes were located on each temple in line with the eyes and one electrode above and below one eye in a vertical line. A fifth electrode was attached to the forehead for a ground to reduce noise. Head movements were measured by an electromechanical linkage system secured to the pilot's helmet, with potentiometers measuring the horizontal and vertical components. The tasks involved fixating on a specific control or display designated by the experimenter. Each task started with eye and head stabilized at a predetermined 0° reference point. Twenty-five tasks were performed for each configuration. The order of configuration presentation was independently randomized for each of the pilots to minimize possible bias due to progressive errors. The results of the 4x8x25 factorial design were evaluated by an analysis of variance for each of the criterion measures.

<u>Vertical Eye/Head Motion</u> - Table 20 summarizes the results of variance tests for the eye and head vertical components. Considering the combined findings, all main and interaction effects showed significant differences at the .01 level, with the exception of the main effect (C) for the configurations which were the primary factor levels of experimental interest. Configuration means for vertical eye motion, when analyzed independently, revealed differences which may have been obscured in the averaging process used to combine data. Therefore, multiple comparisons of configuration means were conducted for vertical eye/head movement as well as vertical eye movement itself. The results, shown in Tables 21 and 22, indicate that Configuration E at 20° yielded significantly larger vertical eye/head movements than Configurations A and B at 65°. Configuration D at 20° was also significantly higher than A at 65°. When the 20° and 65° means were combined, the range of means was 24.95° to 31.48°. The order from low to high was A, B, D, and E. None of the pairs was significantly different.

For vertical eye movements alone, the significant differences were solely between seat angles. Configurations A, D and E at 20° seat angle required larger vertical eye movements than all configurations at 65°. For the same seat angle, the magnitude of vertical eye movements was comparable across configurations. The differences tend to average out when combining the results of 20° and 65° so that no one configuration appeared significantly better than another, using this approach. The results of this combination yielded B=9.15°, D=11.04°, E=11.47° and A=11.47°

TABLE 20
VERTICAL EYE/HEAD MOVEMENT ANOVA

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F
EYE				
Pilots	3	16401.36	5467.12	54.47*
Configurations	7	14373.30	2053.33	3.73*
Tasks	24	43559.56	1814.98	4.16*
Pilots x Configurations	21	11566.14	550.77	5.49*
Pilots x Tasks	72	31398.19	436.09	4.34*
Configurations x Tasks	168	19924.64	118.60	1.18
Residual	504	50588.94	100.37	
Total	799	187812.06		
HEAD				
Pilots	3	8549.16	2849.72	81.40*
Configurations	7	6224.32	889.19	1.26
Tasks	24	125803.99	5241.83	42.72*
Pilots x Configurations	21	14771.92	703.42	20.09*
Pilots x Tasks	72	8834.20	122.70	3.50*
Configurations x Tasks	168	14924.44	88.84	2.54*
Residual	504	17644.88	35.01	
Total	799	196752.81		
TOTAL				
Pilots	3	19217.79	6405.93	52.60*
Configurations	7	15785.83	2255.12	2.06
Tasks	24	266404.42	11100.18	25.00*
Pilots x Configurations	21	23089.18	1099.48	9.03*
Pilots x Tasks	72	31969.73	444.02	3.65*
Configurations x Tasks	168	33000.81	196.43	1.61*
Residual	504	61382.44	121.79	
Total	799			

* Significant ($P < .01$)

TABLE 21
VERTICAL EYE MOVEMENT MEANS
Duncan's Multiple Range Test
Degrees

Config.		(1) B65	(2) E65	(3) A65	(4) D65	(5) B20	(6) D20	(7) A20	(8) E20	Shortest Significant Range	
	Mean	-6.14	-6.59	-6.86	-7.27	-12.16	-14.80	-16.07	-16.34	.05**	.01*
(1)	-6.14	-	0.45	0.72	1.13	6.02	8.66**	9.93**	10.20*	R_2=6.51	8.56
(2)	-6.59		-	0.27	0.68	5.57	8.21**	9.48**	9.75*	R_3=6.86	8.93
(3)	-6.86			-	0.41	5.30	7.94**	9.21**	9.48**	R_4=7.10	9.17
(4)	-7.27				-	4.89	7.53**	8.80**	9.07**	R_5=7.26	9.35
(5)	-12.16					-	2.64	3.91	4.18	R_6=7.40	9.49
(6)	-14.80						-	1.27	1.54	R_7=7.49	9.61
(7)	-16.07							-	0.27	R_8=7.59	9.73

*Significant (P<.01)
**Significant (P<.05)

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

TABLE 22
VERTICAL EYE/HEAD MOVEMENT MEANS
Duncan's Multiple Range Test
Degrees

Config.		(1) A65	(2) B65	(3) E65	(4) D65	(5) B20	(6) A20	(7) D20	(8) E20	Shortest Significant Range	
	Mean	-21.63	-24.06	-27.18	-27.42	-27.63	-28.26	-34.38	-35.78	.05**	.01*
(1)	-21.63	-	2.43	5.55	5.79	5.67	6.63	12.75**	14.15*	R_2=9.20	12.08
(2)	-24.06		-	3.12	3.36	3.57	4.20	10.32	11.72**	R_3=9.69	12.62
(3)	-27.18			-	0.24	0.45	1.08	7.20	8.60	R_4=10.03	12.95
(4)	-27.42				-	0.21	0.84	6.96	8.36	R_5=10.26	13.21
(5)	-27.63					-	0.63	6.75	8.15	R_6=10.46	13.41
(6)	-28.26						-	6.12	7.52	R_7=10.59	13.58
(7)	-34.38							-	1.40	R_8=10.72	13.74

*Significant (P<.01)
**Significant (P<.05)

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

The main effect (T) is a comparison of mean vertical eye/head motion among the 25 tasks averaged over eight configurations and four pilots. This yielded a significant variance. This result, in combination with similar findings for the CxT (configurations X tasks) and PxT (pilots X tasks) interactions, indicated that certain tasks in specific configuration and pilot contexts would require larger eye/head movements than others. Tables 23, 24, and 25 describe the tasks and tabulate the means and standard deviations based upon n=4 observations per task per configuration. The standard error of the mean, computed only for the total vertical component, represents the standard deviation of the sampling distribution of means for a given task averaged across the eight configurations. Tasks yielding significant pairs of difference were determined by use of multiple range tests. These test results are summarized in Tables 56 to 65 in Appendix B. The tasks were:

1. Ground Power Avionics On
3. Auxiliary Power
8. Landing Lights
9. Landing Gear
10. FBW AFCS Master
13. Push to Jettison
18. Anti-Ice Pitot Heat On
20. Lights Console
22. Decoy Panel
24. MSD 2

By a simple count of significant pairs, Configuration D at 20° and 65° and Configuration E at 20° showed increased vertical eye/head movements for more tasks than other configurations.

Horizontal Eye/Head Motion - The analyses of variance for horizontal eye/head components are summarized in Table 26.

Considering the combined horizontal component, the main effect (T) and the three interaction effects revealed significant variances. The fact that pilot variations in eye motion and head motion as separate measures were significant would seem to indicate that head and eye movement patterns were different. But when the total movement was computed, the counterbalancing effect of the 2 sets of data had nullified the independent differences. One pilot might exhibit more eye motion than head motion, while another more head motion than eye motion. The main effect (C), whose means are derived by averaging over four pilots and 25 tasks, was not significant for the individual or combined horizontal components. The configuration means ranged from -7.86° for A at 65° to -11.12° for D at 20°. None of the configurations differed significantly when systematically paired and tested. When the results of 20° and 65° were combined, the following order was derived: A=-7.94°, E=-9.17°, B=-9.56°, and D=-10.78°. Again, the magnitude of the difference for any pair failed to meet the .05 criterion level for significant testing. Main effect (T), a comparison of mean horizontal eye/head motion among the 25 tasks averaged over eight configurations and four pilots, yieled a significant variance. This result, in combination with similar

TABLE 23
VERTICAL EYE MOVEMENT
Degrees

TASK NO.	TASK DESCRIPTION	A20 MEAN	A20 S.D.	A65 MEAN	A65 S.D.	B20 MEAN	B20 S.D.	B65 MEAN	B65 S.D.	D20 MEAN	D20 S.D.	D65 MEAN	D65 S.D.	E20 MEAN	E20 S.D.	E65 MEAN	E65 S.D.
1	GROUND POWER AVIONICS ON	-25.00	7.94	-12.75	4.27	-29.50	8.70	-19.00	9.76	-32.75	12.82	-16.25	10.72	-23.00	9.20	-18.75	11.18
2	EMERGENCY SPEED BRAKE	-24.25	25.60	-20.00	14.45	-20.50	12.23	-13.00	13.88	-17.75	11.03	-21.25	13.06	-22.25	14.43	-17.25	4.11
3	AUXILIARY POWER	-27.75	13.40	-17.75	15.11	-11.00	4.08	-11.50	7.77	-14.75	4.79	-14.00	11.75	-17.50	7.33	- 7.25	8.54
4	TACAN BIT	-27.25	17.75	-21.50	16.20	-24.00	8.41	-21.25	16.26	-23.25	5.32	-13.50	7.55	-25.75	5.85	-14.50	19.26
5	UHF COMMUNICATION CHANNEL	-25.50	15.70	-18.25	6.70	-18.25	12.56	-19.00	10.89	-18.00	4.62	-19.50	6.56	-25.00	12.99	-20.75	9.29
6	UHF COMMUNICATION CHANNEL/FREQUENCY	-25.75	17.63	-14.50	11.93	-21.50	5.74	-22.75	18.93	-26.25	5.06	-23.00	12.94	-31.50	13.48	-24.75	9.36
7	SELECT JETTISON COMBAT/STORES	-25.75	20.77	-14.75	9.03	-15.00	6.83	-19.75	16.94	-22.75	8.96	-18.75	2.22	-19.00	12.83	-20.75	14.13
8	LANDING LIGHTS	-19.00	15.58	0.00	9.09	- 8.25	4.57	- 6.50	6.25	-15.00	15.25	- 1.50	6.81	-20.75	7.32	1.75	6.80
9	LANDING GEAR	-13.75	6.24	- 6.25	12.84	- 6.25	2.06	- 5.50	11.79	-16.00	15.90	-23.50	10.08	-21.50	12.37	-13.25	[illegible]
10	FBW AFCS MASTER	-22.00	13.56	-10.25	9.25	-14.50	5.26	-10.25	3.77	-18.50	11.36	-14.75	5.56	-19.75	6.95	-15.50	5.80
11	FUEL QUANTITY	- 0.25	2.99	0.75	5.38	- 0.50	4.65	4.75	5.19	0.25	5.50	4.00	7.35	3.25	6.29	[illegible]	4.27
12	JAMMER PUSH BUTTON	- 9.50	5.92	1.00	13.09	- 6.50	4.12	0.75	6.50	- 6.25	3.10	- 7.75	17.84	-13.00	2.83	- 6.00	4.08
13	PUSH TO JETTISON	- 3.50	0.58	3.50	1.00	- 0.50	3.87	- 0.25	4.27	- 2.00	8.60	13.00	21.48	- 3.75	4.03	- 5.75	3.30
14	MASTER ARM	- 1.50	1.73	- 5.25	5.12	- 2.75	4.57	- 1.75	6.95	- 4.25	6.24	- 4.00	1.83	- 4.00	5.94	- 2.50	3.00
15	VI MASTER MODE	2.25	9.91	- 4.75	1.26	- 3.25	2.22	- 2.00	5.35	- 3.25	4.86	- 0.75	4.35	- 5.00	1.41	0.00	8.04
16	MASTER CAUTION	- 5.50	5.80	- 1.25	3.86	- 4.00	1.63	0.25	7.27	- 2.50	6.76	1.50	4.43	- 5.00	1.83	- 1.50	2.89
17	MSD I RADAR MODE	- 9.25	4.57	- 6.25	8.46	- 9.50	2.65	- 2.75	7.09	-16.75	8.30	- 7.50	4.20	- 9.25	6.08	-10.00	4.08
18	ANTI-ICE PITOT HEAT ON	-18.50	18.27	- 7.75	14.15	-14.75	8.50	- 0.25	11.09	-26.75	10.50	- 9.00	28.74	-28.50	9.95	- 5.75	18.55
19	TEMPERATURE PANEL AIR SOURCE OFF TO BOTH	-22.75	20.56	- 5.50	22.84	-14.25	15.33	2.75	14.52	-12.75	14.77	- 3.50	17.06	-14.75	13.82	- 4.50	17.25
20	INTERNAL LIGHTS CONSOLE OFF TO BRIGHT	-25.75	19.94	- 8.00	22.72	-14.75	9.03	- 7.00	8.60	-22.75	6.50	- 8.75	14.66	-21.50	13.08	- 8.00	21.68
21	EXTERNAL LIGHTS FORMATION OFF TO DIM	-17.50	12.69	- 0.50	29.23	-15.75	9.22	0.75	15.20	-13.50	9.88	- 4.00	16.83	-20.50	9.33	16.25	60.74
22	DECOY PANEL CHAFF UNITS/BURST 3 TO C	-19.75	12.09	- 8.25	24.93	- 6.25	18.43	11.25	36.23	-19.75	8.09	1.25	17.58	-18.50	8.35	- 2.75	22.69
23	DECOY PANEL FLARES INTERVAL 2 TO 12	-19.75	13.65	-10.00	37.18	-20.00	3.92	- 5.50	18.63	-15.00	10.86	14.50	61.34	-22.00	11.86	15.75	39.71
24	MSD 2	-10.50	8.35	- 4.50	12.61	-18.00	4.16	- 6.50	3.42	-12.25	0.96	- 5.50	16.66	-13.00	4.69	3.75	13.05
25	MSD 4	- 3.50	3.00	1.25	4.27	- 9.50	9.11	0.50	5.80	- 6.50	4.51	0.76	12.92	- 7.00	5.29	- 4.00	4.69

TABLE 24
VERTICAL HEAD MOVEMENT
Degrees

TASK NO.	TASK DESCRIPTION	A20		A65		B20		B65		D20		D65		E20		E65	
		MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
1	GROUND POWER AVIONICS ON	-30.25	19.75	-33.00	21.31	-41.25	4.16	-39.00	8.98	-36.25	7.09	-45.00	4.08	-43.00	8.04	-46.00	5.72
2	EMERGENCY SPEED BRAKE	-13.25	8.67	-11.00	7.79	-19.75	4.11	-21.00	8.20	-22.75	7.80	-17.75	5.85	-20.00	7.79	-21.50	5.51
3	AUXILIARY POWER	-16.50	14.17	-29.75	19.36	-12.75	2.50	-14.25	9.54	-15.50	6.61	-16.50	7.85	-14.25	6.40	-14.25	6.50
4	TACAN BIT	-26.50	17.90	-31.75	20.01	-36.75	4.03	-38.50	9.18	-36.25	8.42	-38.75	5.97	-37.50	8.58	-34.00	14.97
5	UHF COMMUNICATION CHANNEL	-21.75	16.94	-21.50	15.15	-32.50	6.81	-28.00	8.12	-29.75	8.85	-30.50	5.20	-31.25	9.54	-26.75	12.97
6	UHF COMMUNICATION CHANNEL/FREQUENCY	-30.75	27.54	-21.50	15.55	-34.00	3.56	-33.00	10.30	-33.75	9.07	-27.25	11.79	-32.00	9.20	-26.00	13.22
7	SELECT JETTISON COMBAT/STORES	-16.00	12.33	-18.00	12.64	-26.00	5.35	-27.25	11.32	-24.75	8.42	-25.50	9.47	-23.25	6.40	-21.75	14.73
8	LANDING LIGHTS	-9.00	9.90	-8.25	8.85	-14.00	5.16	-14.50	8.23	-24.50	6.46	-29.00	11.17	-19.50	6.40	-42.75	6.34
9	LANDING GEAR	-2.75	2.06	-4.50	6.60	-3.50	1.29	-8.25	8.54	-22.00	4.97	-16.50	8.70	-20.25	6.85	-23.00	8.68
10	FBW APCS MASTER	-8.75	9.00	-8.75	4.99	-17.25	8.16	-13.75	7.37	-21.25	2.99	-16.75	4.27	-18.50	6.14	-19.25	6.99
11	FUEL QUANTITY	-4.75	2.63	-9.25	5.91	-8.50	2.15	-10.25	4.79	-7.50	7.37	-9.50	9.75	-10.50	8.35	-10.00	10.39
12	JAMMER PUSH BUTTON	-3.00	2.83	-6.25	5.74	-4.25	3.10	-7.25	2.36	-2.25	2.22	-3.25	5.25	-2.25	2.06	-0.75	3.30
13	PUSH TO JETTISON	0.0	0.82	-1.25	0.0	-1.25	0.95	-2.25	1.71	-1.50	0.58	-2.50	3.87	-0.00	0.82	1.75	4.19
14	MASTER ARM	-2.00	0.82	-0.25	0.05	-1.50	1.29	-5.50	7.23	-0.50	1.00	-1.75	3.59	-0.25	0.96	-1.75	1.71
15	"VI" MASTER MODE	0.0	0.82	0.00	1.63	-1.00	0.82	-2.75	4.19	-0.50	1.00	-1.75	2.87	-2.25	0.96	-1.50	2.38
16	MASTER CAUTION	0.50	1.29	0.00	0.82	-0.00	0.82	-3.50	7.04	-0.25	0.96	-3.00	2.71	0.50	1.29	-1.75	3.59
17	"MSD1" RADAR MODE	-0.25	0.50	-1.00	1.41	-1.50	1.28	-4.00	6.78	-1.25	1.26	-4.50	5.45	-2.00	0.00	-3.25	5.19
18	ANTI-ICE PILOT HEAT ON	-7.25	7.93	-18.50	11.62	-10.50	8.10	-17.75	8.26	-37.25	8.66	-40.00	10.23	-38.00	8.37	-42.25	11.76
19	TEMPERATURE PANEL AIR SOURCE OFF TO BOTH	-16.50	13.67	-18.75	11.93	-18.25	12.09	-22.50	7.19	-27.25	11.09	-21.50	8.70	-27.50	9.26	-25.25	10.14
20	INTERIOR LIGHTS OFF TO BRIGHT	-22.75	16.76	-24.50	15.80	-20.75	9.39	-30.25	4.43	-36.75	10.37	-33.25	14.98	-33.50	6.19	-33.50	11.45
21	EXTERIOR LIGHTS OFF TO DIM	-23.75	16.46	-29.50	20.11	-20.75	10.72	-31.25	8.10	-24.00	26.81	-34.25	10.21	-31.00	7.70	-33.75	11.09
22	DECOY CHAFF UNITS/BURST 3 TO C	-23.00	16.39	-28.50	18.08	-24.50	9.15	-31.00	7.53	-36.50	5.80	-36.50	12.12	-34.25	9.39	-34.75	7.27
23	DECOY FLARES - INTERVAL 8 TO 12	-28.25	17.88	-34.25	22.25	-30.00	9.83	-30.25	7.32	-40.25	10.53	-41.00	14.17	-38.25	10.50	-45.00	10.49
24	MSD2	-3.25	3.86	-7.00	8.98	-4.50	2.38	-6.75	4.12	-5.00	2.16	-4.75	5.50	-5.25	3.50	-5.50	6.56
25	MSD4	-1.25	1.89	-2.25	3.17	-1.75	2.06	-5.25	4.99	-2.25	2.22	-2.75	5.85	-2.00	2.58	-2.25	2.22

TABLE 25
VERTICAL EYE/HEAD MOVEMENT
Degrees

TASK NO.	TASK DESCRIPTION	CODE	A20		A65		B20		B65		D20		D65		E20		E65		STD ERROR OF MEAN
			MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	
1	GROUND POWER AVIONICS ON	**	-55.75	25.00	-45.75	22.17	-70.75	9.54	-58.00	8.45	-69.00	11.23	-61.25	14.66	-66.00	11.75	-64.75	16.62	7.46
2	EMERGENCY SPEED BRAKE	NS	-37.50	28.22	-31.00	14.76	-40.25	11.70	-34.00	17.57	-40.50	10.47	-39.00	8.12	-42.25	16.64	-38.75	5.62	7.07
3	AUXILIARY POWER	*	-43.75	18.30	-47.50	26.30	-23.75	3.59	-25.75	4.58	-30.25	2.22	-30.50	6.14	-31.75	5.85	-21.50	14.06	5.07
4	TACAN BIT	NS	-53.75	23.64	-53.25	29.19	-60.75	8.06	-59.75	14.01	-59.50	7.77	-52.25	12.28	-63.25	12.31	-48.50	16.34	7.72
5	UHF COMMUNICATION CHANNEL	NS	-47.25	21.36	-39.75	15.31	-50.75	6.70	-47.00	7.44	-47.75	3.50	-50.00	3.46	-56.25	12.09	-47.50	20.42	5.64
6	UHF COMMUNICATION CHANNEL/FREQUENCY	NS	-51.25	22.82	-36.00	15.03	-55.50	6.46	-55.75	18.26	-60.00	10.89	-50.25	17.15	-63.50	14.46	-50.75	18.15	7.70
7	SELECT JETTISON COMBAT/STORES	NS	-41.75	21.12	-32.75	14.57	-41.00	6.38	-47.00	18.13	-47.50	1.73	-44.25	8.73	-42.25	9.11	-42.50	11.27	5.70
8	LANDING LIGHTS	*	-28.00	18.49	- 8.25	13.25	-22.25	6.40	-21.00	6.27	-39.50	9.15	-30.50	8.50	-40.25	7.27	-41.00	4.90	4.33
9	LANDING GEAR	*	-16.50	6.35	-10.75	7.93	- 9.75	3.20	-13.75	7.27	-38.00	13.95	-40.00	7.87	-41.75	8.06	-36.25	11.27	4.12
10	FBW AFLS MASTER	*	-30.75	18.15	-19.00	9.57	-31.75	2.87	-24.00	7.30	-39.75	12.04	-31.50	2.38	-38.25	4.99	-34.75	12.66	4.06
11	FUEL QUANTITY	NS	- 5.00	8.94	- 8.50	7.55	- 9.00	4.55	- 5.50	3.11	- 7.25	3.77	- 5.50	3.70	- 7.25	3.30	- 8.75	7.68	2.29
12	JAMMER PUSH BUTTON	NS	-12.50	8.50	- 5.25	10.69	-10.75	1.71	- 6.50	8.23	- 8.50	2.65	-11.00	12.96	-15.25	3.10	- 6.75	6.13	6.75
13	PUSH TO JETTISON	*	- 3.50	0.58	2.25	0.96	- 1.75	2.99	- 2.50	3.87	- 3.50	9.04	10.50	18.05	- 3.75	3.59	- 4.00	2.31	2.59
14	MASTER ARM	NS	- 3.50	1.73	- 5.50	4.43	- 4.25	4.11	- 7.25	9.39	- 4.75	6.29	- 5.75	3.30	- 4.25	5.91	- 4.25	[illegible]	2.35
15	VI MASTER MODE	NS	2.25	10.37	- 4.75	0.50	- 4.25	2.22	- 4.75	3.86	- 3.75	5.56	- 2.50	4.51	- 7.25	2.22	- 1.50	[illegible]	2.25
16	MASTER CAUTION	NS	- 5.00	6.93	- 1.25	4.35	- 4.00	2.16	- 3.25	0.96	- 2.75	7.66	- 1.50	5.69	- 4.50	9.58	- 3.25	4.35	2.04
17	HSD 1 RADAR MODE	NS	- 9.50	4.12	- 7.25	8.96	-11.00	1.41	- 6.75	8.22	-18.00	8.21	-12.00	2.16	-11.25	6.08	-13.25	4.65	2.18
18	ANTI-ICE PITOT HEAT ON	*	-25.75	15.78	-26.25	22.64	-25.25	6.13	-18.00	9.20	-63.75	7.37	-49.00	30.28	-66.50	7.59	-48.00	16.99	7.31
19	TEMPERATURE PANEL AIR SOURCE OFF TO BOTH	NS	-39.25	25.20	- 4.25	32.55	-32.50	5.45	-19.75	15.33	-40.00	3.74	-25.00	13.09	-42.25	5.38	-29.75	12.69	7.09
20	INTERIOR LIGHTS CONSOLE OFF TO BRIGHT	*	-48.50	23.33	-12.50	32.73	-35.50	3.11	-37.25	9.91	-59.50	6.56	-42.00	15.43	-55.00	10.03	-41.50	21.58	7.67
21	EXTERIOR LIGHTS FORMATION OFF TO DIM	NS	-41.25	17.88	-30.00	43.50	-36.50	3.70	-30.50	16.78	-37.50	32.85	-38.25	13.94	-51.50	4.80	-17.50	58.93	12.02
22	DECOY PANEL CHAFF UNITS BURST 3 TO C	*	-42.75	19.16	-36.75	36.77	-30.75	27.11	-19.75	36.58	-56.25	6.60	-35.25	15.78	-52.75	5.68	-37.50	19.89	8.17
23	DECOY PANEL FLARES INTERVAL 2 TO 12	NS	-47.50	21.32	-24.25	55.13	-50.00	7.02	-35.75	19.75	-56.25	2.87	-26.50	57.55	-60.25	9.18	-29.25	38.98	12.05
24	HSD 2	*	-13.75	5.85	-11.50	12.50	-17.50	5.07	-13.25	3.40	-17.25	2.99	-10.25	18.73	-18.25	2.50	- 1.75	11.56	3.92
25	HSD 4	NS	- 4.75	1.50	- 1.00	5.48	-11.25	10.59	- 4.75	7.59	- 8.75	3.86	- 2.00	9.35	- 9.00	2.83	- 6.25	2.63	2.74

NS - Not Significant
* - Significant (P < .01)
** - Significant (P < .05)

TABLE 26
HORIZONTAL EYE/HEAD MOVEMENT ANOVA

SOURCE OF VARIATION	SOURCE OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F
EYE				
Pilots	3	2328.07	776.02	19.11*
Configurations	7	946.60	135.23	0.71
Tasks	24	219565.69	9148.57	46.26*
Pilots x Configurations	21	3961.62	188.65	4.65*
Pilots x Tasks	72	14239.05	197.76	4.87*
Configurations x Tasks	168	16881.20	100.48	2.47*
Residual	504	20464.81	40.60	
Total	799	278386.88		
HEAD				
Pilots	3	2427.58	809.19	7.93*
Configurations	7	2788.01	398.29	1.95
Tasks	24	457478.50	19061.60	70.96*
Pilots x Configurations	21	4283.29	203.97	2.00*
Pilots x Tasks	72	19342.08	268.64	2.63*
Configurations x Tasks	168	47673.73	283.77	2.78*
Residual	504	51424.44	102.03	
Total	799	585417.50		
TOTAL				
Pilots	3	113.38	37.79	0.39
Configurations	7	1121.62	160.23	0.90
Tasks	24	1277818.28	53242.43	368.87*
Pilots x Configurations	21	3730.60	177.65	1.82**
Pilots x Tasks	72	10392.15	144.34	1.46**
Configurations x Tasks	168	22026.34	190.63	1.95*
Residual	504	49290.00	97.80	
Total	799	1374491.00		

* Significant (P < .01)
** Significant (P < .05)

findings for the CxT (configurations X tasks) and PxT (pilots X tasks) interactions, indicated that certain tasks in specific configuration and pilot contexts would require larger eye/head movements than others. Tables 27, 28, and 29 describe the tasks and tabulate the means and standard deviations based upon n=4 observations per task per configuration. The standard error of the mean, computed only for the total horizontal component, represents the standard deviation of the sampling distribution of means for a given task averaged across the eight configurations. Tasks yielding significant pairs of difference were determined by use of multiple range tests. These test results are summarized in Tables 66 to 85 in Appendix B. All tasks which exhibited significant variations on the vertical eye/head plane also showed significant differences in the horizontal eye/head plane. Increased total horizontal motion was revealed for the following additional tasks:

2. Emergency Speed Brake
4. BIT TCN
5. UHF Communications Channel
7. Select Jettison - Combat to Stores
12. Jammer Pushbutton
14. Master Arm
15. V' Master Mode
19. Temperature Panel Air Source Off to Both
23. Decoy Panel Flares Interval
25. MSD 4

By a simple count of significant pairs, Configurations D and E at 20° showed increased horizontal eye/head movements for more tasks than other configurations.

TABLE 27
HORIZONTAL EYE MOVEMENT
Degree

TASK NO.	TASK DESCRIPTION	A20		A65		B20		B65		D20		D65		E20		E65	
		MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
1	GROUND POWER AVIONICS ON	-25.75	7.90	-29.50	9.26	-22.75	14.22	-31.75	15.11	-25.00	14.58	-32.75	15.56	-25.00	10.16	-36.50	13.33
2	EMERGENCY SPEED BRAKE	-25.00	3.83	-22.50	8.54	-16.00	3.83	-26.00	12.30	-15.00	5.48	-28.75	4.86	-18.50	6.86	-21.75	12.51
3	AUXILIARY POWER	-19.00	8.83	-19.00	5.60	-10.25	4.99	-17.75	7.87	-6.25	7.04	-20.75	4.57	-11.50	3.11	-6.00	14.89
4	TCN BIT	-21.00	3.57	-25.00	11.23	-19.25	11.53	-35.50	13.77	-22.25	16.11	-31.75	13.74	-23.25	11.03	-35.00	11.92
5	UHF COMM CHANNEL	-14.00	3.56	-24.25	4.35	-12.25	8.54	-25.00	15.94	-15.50	8.14	-26.75	12.94	-16.75	4.79	-26.75	14.83
6	UHF COMM CHANNEL/FREQUENCY	-13.25	5.38	-21.50	10.41	-7.50	8.55	-25.50	9.57	-12.25	13.72	-25.00	10.89	-12.75	8.17	-26.50	7.94
7	SELECT JETTISON COMBAT/STORES	-9.75	5.44	-17.50	8.10	-10.25	5.50	-19.50	6.86	-11.50	9.26	-24.00	19.41	-12.25	9.17	-21.50	9.00
8	LANDING LIGHTS	-19.25	8.64	-16.50	9.11	-10.00	3.16	-12.50	7.12	-21.00	6.69	-16.00	7.12	-11.25	15.82	-7.25	9.67
9	LANDING GEAR	-22.00	10.23	-16.25	7.81	-15.50	7.90	-15.50	6.86	-13.75	8.80	-17.75	10.53	-13.00	8.91	-19.75	17.42
10	FBW AFCS MASTER	-13.25	10.31	-14.50	4.80	-6.25	7.81	-18.50	8.43	-13.75	9.82	-23.00	12.68	-8.50	5.80	-21.00	16.89
11	FUEL QUANTITY	1.00	2.45	7.25	6.24	9.25	4.65	4.75	6.13	7.50	5.16	3.25	11.82	12.75	5.85	1.50	12.01
12	JAMMER PUSH BUTTON	-15.25	5.91	-11.75	7.93	-12.00	5.89	-2.25	11.00	-16.50	4.12	-15.75	8.85	-17.75	7.27	-15.00	7.12
13	PUSH TO JETTISON	-8.50	4.20	-10.50	1.73	-6.25	4.11	-6.25	7.76	-6.50	3.00	-11.00	4.19	-6.75	3.77	-8.75	1.89
14	MASTER ARM	-9.75	6.75	-11.75	7.89	-16.50	5.45	-6.25	4.92	-18.75	3.00	-16.00	5.60	-19.00	6.78	-15.75	4.27
15	VI MASTER MODE	-11.00	3.27	-9.25	0.96	-11.00	4.08	-11.00	3.16	-14.25	3.86	-10.75	2.06	-10.00	3.66	-11.00	1.83
16	MASTER CAUTION	-1.25	2.83	-1.25	1.50	-0.75	1.71	-3.00	5.16	-4.00	2.45	-3.00	3.16	0.50	1.73	-2.00	2.16
17	MSD 1 RADAR MODE	-2.25	2.06	-3.75	6.79	-2.00	1.83	-0.25	2.82	-0.25	3.40	-1.00	2.83	-0.25	4.19	-3.00	3.27
18	ANTI-ICE PITOT HEAT ON	15.25	7.50	9.25	8.34	19.00	5.60	16.75	6.90	20.25	6.45	29.00	3.17	19.75	6.65	21.25	10.78
19	TEMPERATURE PNL AIR SOURCE OFF TO BOTH	13.50	7.90	18.75	11.03	16.50	5.00	25.50	8.15	12.25	3.69	21.00	11.57	15.75	7.27	19.50	8.89
20	INTERIOR LIGHTS CONSOLE OFF TO BRIGHT	13.25	7.[illegible]	26.00	5.29	15.00	7.70	26.50	5.16	15.00	2.16	25.75	8.38	18.25	7.83	22.50	6.56
21	EXTERIOR LIGHTS FORMATION OFF TO DIM	15.50	7.68	23.75	11.84	18.50	3.70	27.75	9.89	10.75	22.13	26.25	7.10	17.25	7.50	24.50	7.59
22	DECOY PANEL CHAFF UNITS BURST 3 TO C	14.25	8.42	18.00	8.53	11.00	17.15	30.75	14.12	24.50	8.15	36.75	7.14	22.25	7.87	24.75	4.57
23	DECOY PANEL FLARES INTERVAL 2 TO 12	20.00	5.35	27.50	8.70	17.50	4.80	37.50	11.18	26.50	6.16	36.75	7.67	20.75	6.70	23.25	9.87
24	MSD 2	-0.75	2.63	-0.00	1.63	1.25	2.22	1.50	4.51	0.00	2.16	1.25	3.09	4.00	6.32	-1.00	3.27
25	MSD 4	7.50	5.20	2.00	0.82	10.75	4.65	5.50	4.66	8.00	5.68	3.25	6.85	8.00	3.56	6.50	3.70

TABLE 28
HORIZONTAL HEAD MOVEMENT
Degrees

TASK NO.	TASK DESCRIPTION	A20		A65		B20		B65		D20		D65		E2C		E65	
		MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.
1	GROUND POWER AVIONICS ON	-37.00	23.31	-29.00	23.99	-42.50	22.23	-37.50	15.02	-58.00	22.11	-28.75	14.31	-58.00	10.86	-32.50	11.03
2	EMERGENCY SPEED BRAKE	-28.25	18.39	-20.25	12.26	-41.75	7.93	-27.50	3.11	-50.00	14.02	-21.50	3.51	-42.[illegible]	7.14	-31.50	9.57
3	AUXILIARY POWER	-26.75	19.77	-26.00	16.83	-33.00	1.41	-19.25	1.70	-39.25	4.57	-21.00	8.04	-35.00	3.16	-24.75	5.44
4	TACAN BIT	-33.00	20.05	-25.75	17.21	-48.00	17.66	-24.75	12.28	-57.50	26.66	-27.50	13.23	-53.00	11.58	-28.75	10.37
5	UHF COMMUNICATION CHANNEL	-32.00	21.74	-18.50	11.27	-42.75	8.66	-24.25	8.10	-43.75	9.00	-24.75	8.22	-39.50	3.32	-24.25	10.21
6	UHF COMMUNICATION CHANNEL/FREQUENCY	-32.50	22.10	-18.75	11.79	-40.50	16.62	-25.75	18.84	-38.50	12.92	-22.00	8.17	-39.75	10.69	-18.50	6.95
7	SELECT JETTISON COMBAT/STORES	-30.00	20.70	-19.25	12.92	-40.75	4.99	-21.25	3.86	-38.00	9.42	-24.75	6.85	-43.75	3.86	-23.25	3.30
8	LANDING LIGHTS	-11.00	11.58	-10.25	7.46	-19.50	2.38	-12.75	10.05	-19.50	11.12	-28.25	19.97	-28.75	11.12	-36.50	4.73
9	LANDING GEAR	- 9.25	8.38	-10.75	7.41	-21.50	2.38	-15.50	6.95	-34.50	6.40	-27.50	7.72	-36.75	8.22	-24.75	11.35
10	FBW AFCS MASTER	-12.25	12.45	-12.50	7.55	-21.00	5.60	-15.25	7.63	-28.25	7.27	-20.25	9.32	-36.75	4.27	-21.75	9.22
11	FUEL QUANTITY	- 8.25	5.12	-13.25	8.66	-10.75	3.77	-10.00	5.77	-11.50	6.19	-11.75	11.87	-11.00	5.29	-11.50	12.58
12	JAMMER P/B	- 6.00	4.08	- 8.50	7.05	-12.75	8.50	-16.25	7.14	-11.50	3.79	- 5.50	8.54	- 7.75	5.75	- 9.50	6.86
13	PUSH TO JETTISON	- 2.00	2.16	- 2.75	1.71	- 3.00	2.16	- 1.00	8.41	- 3.75	1.71	- 1.00	4.24	- 2.50	1.73	- 0.25	1.50
14	MASTER ARM	- 5.50	3.70	- 1.75	1.71	- 4.00	4.08	- 7.75	8.58	- 3.75	3.86	0.25	2.99	- 4.50	4.20	- 0.75	1.50
15	VI MASTER MODE	- 0.50	1.00	- 1.25	1.50	- 2.75	0.96	0.75	2.36	- 1.50	5.07	- 0.25	2.50	- 5.25	2.06	- 0.50	2.65
16	MASTER CAUTION	0.0	1.41	- 0.25	1.71	- 0.50	1.29	2.25	3.69	0.50	1.29	- 0.25	6.45	1.50	1.91	1.25	4.65
17	MSD 1 RADAR MODE	1.25	1.26	1.00	2.00	- 0.75	1.71	- 0.75	1.26	- 2.75	1.89	- 0.00	4.97	- 0.00	1.63	1.25	4.72
18	ANTI-ICE PITOT HEAT ON	6.75	13.50	16.00	11.34	12.25	10.87	14.00	11.02	44.00	17.91	17.25	3.59	43.25	6.85	28.75	13.62
19	TEMPERATURE PANEL AIR SOURCE OFF TO BOTH	27.25	23.67	17.25	13.60	19.50	10.72	14.25	14.86	35.00	9.90	18.75	9.07	36.75	13.67	21.25	9.95
20	INTERIOR LIGHTS CONSOLE OFF TO BRIGHT	34.50	30.88	10.00	12.03	27.50	9.57	14.75	11.84	41.25	11.09	14.50	8.02	37.50	13.08	19.25	7.14
21	EXTERIOR LIGHTS FORMATION OFF TO DIM	42.00	32.51	10.00	12.03	33.00	9.20	29.00	15.64	32.75	34.92	23.50	7.51	49.50	14.62	26.75	12.28
22	DECOY CHAFF UNITS/BURST 3 TO C	44.75	32.98	35.50	23.01	35.25	13.23	27.00	13.88	46.25	6.60	23.00	9.56	51.25	9.67	32.75	6.45
23	DECOY FLARES INTERNAL 2 TO 12	46.25	30.83	33.25	23.07	44.50	14.93	24.50	15.67	54.25	2.63	23.50	9.04	56.00	5.03	39.75	16.50
24	MSD 2	0.75	2.22	2.50	3.00	0.50	1.29	1.50	4.51	- 0.75	1.50	0.25	1.71	0.50	3.51	0.25	1.71
25	MSD 4	1.25	0.96	5.25	4.11	4.50	5.57	4.50	2.89	2.50	5.51	4.75	5.56	3.75	3.77	2.75	6.50

TABLE 29
HORIZONTAL EYE/HEAD MOVEMENT
Degrees

TASK NO.	TASK DESCRIPTION	CODE	A20		A65		B20		B65		D20		D65		E20		E65		STD ERROR OF MEAN
			MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.	
1	GROUND POWER AVIONICS ON	NS	-62.75	20.07	-58.50	16.78	-65.25	9.18	-69.25	19.91	-83.00	16.02	-61.50	8.58	-83.00	1.83	-69.00	4.24	7.65
2	EMERGENCY SPEED BRAKE	**	-53.25	20.95	-42.75	11.33	-57.75	5.62	-53.50	11.27	-65.00	13.44	-50.25	6.29	-61.25	6.90	-53.25	5.68	5.08
3	AUXILIARY POWER	**	-45.75	18.12	-45.00	13.29	-43.25	5.44	-37.00	5.94	-45.50	4.04	-41.75	7.68	-46.50	4.04	-30.75	15.06	4.60
4	TCN BIT	*	-54.00	22.67	-50.75	7.09	-67.25	7.09	-60.25	19.28	-79.75	17.15	-59.25	5.06	-76.25	4.72	-63.75	7.68	5.02
5	UHF COMMUNICATION CHANNEL	**	-46.00	24.91	-42.75	8.14	-55.00	5.94	-49.25	8.99	-59.25	6.78	-51.50	4.80	-56.25	5.06	-51.00	8.45	4.57
6	UHF COMMUNICATION CHANNEL/FREQUENCY	NS	-45.75	21.76	-40.25	9.29	-48.00	11.20	-51.25	18.14	-50.75	7.14	-47.00	7.39	-52.50	11.09	-45.00	6.16	5.76
7	SELECT JETTISON COMBAT/STORES	*	-39.75	18.84	-36.75	7.89	-51.00	2.94	-49.75	6.55	-49.50	5.97	-48.50	6.25	-56.00	9.83	-44.75	7.41	4.10
8	LANDING LIGHTS	*	-30.25	9.81	-26.75	2.99	-29.50	5.45	-25.25	4.99	-40.50	0.71	-44.25	9.36	-40.00	4.97	-43.75	8.26	3.47
9	LANDING GEAR	*	-31.25	10.37	-27.00	1.83	-37.00	5.60	-31.00	5.72	-48.25	4.99	-48.50	9.04	-49.75	6.08	-44.50	6.46	3.13
10	FBW AFCS MASTER	**	-25.50	8.51	-22.75	10.67	-27.25	5.44	-33.75	1.26	-42.00	7.57	-42.00	4.62	-45.25	6.08	-24.25	41.66	5.38
11	FUEL QUANTITY	NS	-7.25	4.50	-6.00	3.16	-1.50	3.87	-5.25	2.75	-4.00	4.32	-8.50	0.58	1.75	4.79	-10.00	5.72	3.15
12	JAMMER PUSH BUTTON	**	-21.25	8.22	-20.25	2.99	-24.75	5.06	-18.50	5.26	-28.00	2.58	-18.25	6.90	-25.50	2.52	-24.50	1.73	2.20
13	PUSH TO JETTISON	**	-10.50	3.79	-13.25	3.30	-9.25	3.40	-7.25	1.89	-10.25	1.71	-12.75	4.95	-9.25	2.22	-9.00	1.03	1.44
14	MASTER ARM	*	-15.25	9.85	-13.50	6.35	-20.50	1.91	-14.00	6.48	-22.50	1.00	-17.00	2.71	-23.50	2.65	-16.50	5.20	2.26
15	"VI" MASTER MODE	**	-11.50	4.12	-10.50	1.00	-13.75	3.30	-10.25	3.20	-15.75	3.40	-11.50	2.52	-15.25	2.63	-11.50	3.70	1.49
16	MASTER CAUTION	NS	-1.25	2.06	-1.50	2.38	-1.25	1.50	-0.75	1.71	-3.50	2.38	-3.25	1.50	2.00	0.82	-0.75	3.86	1.01
17	"MSD 1" RADAR MODE	NS	-1.00	2.45	-2.75	7.14	-2.75	2.50	-1.75	2.50	-3.00	1.83	-1.00	2.16	-0.25	5.85	-1.75	3.77	1.76
18	ANTI-ICE PITOT HEAT ON	*	22.00	9.83	25.25	5.32	31.25	5.68	30.75	5.44	64.25	7.54	46.25	3.30	63.00	6.38	50.00	7.44	3.18
19	TEMPERATURE PNL AIR FORCE OFF TO BOTH	*	40.75	16.50	36.00	2.58	36.00	5.94	39.75	8.18	47.25	9.06	39.75	3.30	52.50	6.56	40.75	6.18	3.64
20	INTERIOR LIGHTS OFF TO BRIGHT	*	47.75	23.50	36.00	7.16	42.50	4.51	41.25	10.05	56.25	11.30	40.25	2.36	55.75	5.74	41.75	2.22	4.18
21	EXTERIOR LIGHTS FORMATION OFF TO DIM	NS	57.50	25.90	47.50	9.26	51.50	7.55	56.75	14.50	43.50	55.04	49.75	6.29	66.75	8.30	51.25	5.19	8.25
22	DECOY CHAFF UNITS/BURST 3 TO C	**	59.00	26.55	53.50	16.54	46.25	23.59	57.75	11.79	70.75	9.98	59.75	5.12	73.50	5.68	57.50	4.04	6.45
23	DECOY PANEL FLARES INTERVAL 2 TO 2	**	66.25	27.46	60.75	16.24	62.00	12.78	62.00	12.46	80.75	7.27	50.25	6.60	76.75	5.90	68.00	8.12	6.05
24	MSD 2	*	-0.00	2.00	2.50	3.00	1.75	0.96	3.00	1.83	-0.75	2.63	1.50	3.70	4.50	3.70	-0.75	3.30	1.34
25	MSD 4	**	8.75	5.56	7.25	4.27	15.25	3.42	19.00	2.31	10.50	3.51	8.00	2.83	11.75	0.56	9.25	3.59	1.97

CODES: NS - NOT SIGNIFICANT
* - SIGNIFICANT (P<.01)
** - SIGNIFICANT (P<.05)

SUBJECTIVE TEST RESULTS

The subjective test sessions included the functional task evaluations based upon mission scenario elements, paired comparison questionnaires, final interview questionnaire, and test critique.

These subjective measurements provided:

- o Evaluation of the cockpit designs in terms of physical and performance aspects as related to the mission scenario

- o Determination of indices of pilot workload for configuration alternatives for mission phases

- o Pilot acceptance based on fulfillment of mission functional task objectives using high acceleration cockpit (HAC) configurations.

In general, these results are overwhelmingly positive to the HAC approach, with the basic cockpit design considered effective and usable. A preference was expressed for the console mounted controller configuration (which raised and lowered consonant with seat motion). In addition, all pilot subjects are enthusiastic about the design aid evaluation techniques from the standpoint that the cockpit familiarity obtained allows the user to communicate with a cockpit design team early in the development cycle.

Mission Scenario

Functional task evaluation was based upon discrete mission scenario elements. Subjective measurements of pilot tasks performed within the context of a mission phase were recorded. These measurements were of the following type:

- o For pilot task performance; yes, no, maybe
- o Pilot opinions

The task sequences were narrated by the test conductor, and the pilot evaluated his ability to perform the task. The pilot was able to express his opinion or suggestions concerning the task or associated equipment at any time throughout the test. This test adds a new dimension to the evaluation reflected in the paired comparison data. The paired comparisons yield a relative value for each configuration and mission phase. This mission scenario evaluation is concerned with estimations of whether the pilot tasks can be accomplished at all. It defines responses with respect to whether or not the mission could be accomplished with the given configurations.

The pilot performed tasks for all mission phases before the configuration was changed and test sequence repeated for all the remaining configurations. The mission phase sequence was as follows: preflight, takeoff and climb, cruise, SAM evasion, LGB delivery, strafing pass, air-to-air combat, inflight refueling, approach and landing, and post flight. The seat back angle was 65° for SAM evasion, LGB delivery, strafing pass, and air-to-air combat. The other mission phases were performed with the seat back angle at 20°.

Each of the configurations was evaluated in the design aid, using a counterbalanced start sequence. Each pilot performed the total mission scenario four times, once for each configuration. A total of 1308 individual tasks were evaluated for each pilot in each configuration. These tasks were those required to perform the full mission. The tasks included items of control manipulation, visibility and readability of displays and subjective/objective decisions relating to mission related activities.

There were 176 negative and questionable responses distributed among the total of the 20928 responses. Of these 176 responses 97 were attributed to the integrated avionics panel primarily for Configurations A, D, and E. The use of the comm button in its initial location on the canted throttles was a task which universally received a negative (maybe or no) response. This response is not noted in the subsequent tables on the frequency of response because a preferred comm button location was noted to the pilots. This location, as noted in Section IV, changed all of these specific negative responses to yes responses.

Preflight - The pilot, seated in the design aid and wearing his flight gear, was talked through each task for the first test configuration. For example, "check throttles off" task has a visual cockpit requirement and required subjective test evaluation. The pilot's subjective response to questions concerning his ability to do tasks was recorded (yes, maybe, no). Of the 469 tasks evaluated in this mission segment, 18 had less than complete agreement on the capability to perform the task for all configurations. Table 30 shows the tasks by configuration and the frequency of the yes, no and maybe response data. Of the 18, there was a majority of negative opinion on 10 tasks. All of them involve the use of the avionics panel in Configuration A. This difficulty related to the interference between the throttle and the avionics panel.

TABLE 30
PREFLIGHT TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION D			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
12	Select Comm/AAI on AP	1	3	0	4	0	0	3	1	0	3	1	0
13	Select Comm On	1	3	0	4	0	0	3	1	0	3	1	0
14	Select Man Freq (108.35)	1	3	0	4	0	0	3	1	0	3	1	0
15	Depress Keys for Freq	1	3	0	4	0	0	3	1	0	3	1	0
16	Select Enter	1	3	0	4	0	0	3	1	0	3	1	0
17	Select Chan Select (12)	1	3	0	4	0	0	3	1	0	3	1	0
18	Depress Keys for Chan (12)	1	3	0	4	0	0	3	1	0	3	1	0
19	Select Enter	1	3	0	4	0	0	3	1	0	3	1	0
20	Select Comm Chan	1	3	0	4	0	0	3	1	0	3	1	0
21	Adjust Volume Control	1	3	0	4	0	0	3	1	0	3	1	0
98	Select Nav Mode	3	1	0	4	0	0	3	1	0	3	1	0
174	Select Displays Mode	3	1	0	4	0	0	4	0	0	4	0	0
175	Select MSD 1 On	3	1	0	4	0	0	4	0	0	4	0	0
177	Adjust Brightness as Required	3	1	0	4	0	0	4	0	0	4	0	0
178	Select Auto Cost	3	1	0	4	0	0	4	0	0	4	0	0
183	Select MSD 3 On	3	1	0	4	0	0	4	0	0	4	0	0
184	Select HSD	3	1	0	4	0	0	4	0	0	4	0	0
328	Select Pitot Heat Switch On	3	1	0	4	0	0	4	0	0	4	0	0

Takeoff and Climb - Tasks presented for this phase were those involved in the aircraft takeoff and climb to cruise altitude. Included were standard takeoff procedures, ground roll/runway track, lead formation, instrument takeoff, departure procedures for an IFR climb, and set up for desired cruise conditions. An instrument takeoff was tested, to provide a worst case workload. Four of the 94 tasks involved yielded uncertainty of implementation from some of the 4 pilots. These tasks and the frequency of response data are summarized in Table 31. The primary problem area centered on the landing gear control as the landing gear indicator lights were not readily visible.

TABLE 31
TAKEOFF AND CLIMB TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION D			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
34	Monitor Warning and Caution Lights	4	0	0	4	0	0	4	0	0	3	1	0
48	Retract Landing Gear	3	1	0	4	0	0	2	0	2	1	0	3
64	Select Outbound Radial	4	0	0	2	1	1	4	0	0	4	0	0
92	Check O_2 Quantity Pressure/ Blinker	4	0	0	4	0	0	1	0	3	4	0	0

Cruise - During the outbound cruise leg, the pilot was required to establish the desired cruise condition. Tasks such as: "Monitor vertical velocity indication," which requires cockpit vision and a subjective evaluation, and "Select steering mode," which requires cockpit vision. Left hand manipulation, and also required objective evaluations were performed. Checks on the flight controls, radar system, armament control, navigation, weapon system, and displays were also required during this segment. During the cruise phase 185 tasks were evaluated. Of these 185 tasks uncertainty was indicated by one pilot with respect to performing 7 of the tasks. The primary problems centered on activating and checking out the FBW system. These tasks are summarized in Table 32.

TABLE 32
CRUISE TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION D			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
6	Activate FBW Att Hold	3	1	0	4	0	0	3	1	0	3	1	0
10	Activate FBW Vel. Vec. Hold	3	1	0	4	0	0	3	1	0	3	1	0
14A	Activate FBW DFC, MVR, Fus Aim	3	1	0	4	0	0	3	1	0	3	1	0
33	Activate Master Model (ADI)	4	0	0	4	0	0	3	1	0	3	1	0
45A	Select UHF Channel	4	0	0	4	0	0	3	1	0	3	1	0
81	Activate TEWS	3	0	1	4	0	0	4	0	0	4	0	0
82	Select RWR AAA	3	0	1	4	0	0	4	0	0	4	0	0

SAM Evasion - The SAM evasion task sequence was performed to show pilot ability to perform this mission phase with the different controller and control/display configurations at a seat back angle of 65°. The scenario called for penetration at mid-to-low altitudes. A jinking flight path was established and radar and ECM tasks were performed. In addition, pilots were required to perform visual outside and visual target tasks throughout this segment. Evasive maneuvers were used as required against SAM and AAA threats. Conventional AAA penetration/SAM evasion tactics were used, modified slightly to utilize more fully the direct lift, direct side force, and high acceleration capabilities of the candidate aircraft. Of the 35 tasks 3 tasks received pilot responses of maybe or no. Difficulty was experienced by two pilots in activating the ECM switch on the canted throttles. The other difficulties centered on the ability to use the throttles in Configuration A while reclined. The findings are tabulated in Table 33.

TABLE 33
SAM EVASION TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION D			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
19	Activate ECM	3	1	0	4	0	0	2	1	1	3	1	0
29	Advance Throttles to Max A/B	2	1	1	4	0	0	4	0	0	4	0	0
30	Perform Evasive Maneuvers	2	0	2	4	0	0	4	0	0	4	0	0

Bomb Delivery - The objective for this combat phase was to evaluate the differences in controller configurations at a seat back angle of 65°. Navigation (INS) and radar tasks were initially required to set a target course. Armament control tasks were performed for weapon system selection and arming (e.g., Select LGB on Line) and target detection and recognition was accomplished using an EO system (e.g., Acquire EO potential target). The target was then engaged, and weapon delivery was accomplished by the aircraft.

A visual representation of an aircraft pass on a bridge target was presented on a screen before the pilot. This was in the form of slides of a bombing run. In this manner the realism of the test was heightened. Of the 97 tasks evaluated, 12 received responses of uncertainty. The majority of these responses centered on operating the avionics panel. However, none of the tasks involved a majority of dissent. The results are summarized in Table 34.

TABLE 34
BOMB DELIVERY TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION C			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
25	Select Sensors	3	1	0	4	0	0	3	0	1	3	0	1
26	Select MAP	4	0	0	4	0	0	3	0	1	3	0	1
27	Verify Optimum Radar Range Scan	4	0	0	4	0	0	3	0	1	3	0	1
28	Verify Optimum Radar Elev Scan	4	0	0	4	0	0	3	0	1	3	0	1
28A	Select TDS On	4	0	0	4	0	0	3	0	1	3	0	1
29	Select EO	4	0	0	4	0	0	3	0	1	3	0	1
29A	Select Depr Angle Alt	4	0	0	4	0	0	3	0	1	3	0	1
30	Select LGB Bombs on Line	3	0	1	4	0	0	4	0	0	4	0	0
31	Verify Desired Stations	3	1	0	4	0	0	4	0	0	4	0	0
72	Depress Target Designate	4	0	0	4	0	0	2	2	0	4	0	0
79	Position for Dive	0	2	2	4	0	0	4	0	0	4	0	0
87	Make High-G Pull-Up Maneuver	3	0	1	4	0	0	4	0	0	4	0	0

Strafing Pass - Strafing pass tasks were performed for each of the four configurations at a seat back angle of 65°. In this segment targets of opportunity were sought along a road and visual search tasks were performed using the EO system. A target was recognized, and the pilot initiated radar tracking functions. Direct force capabilities were utilized for offset and slant range tracking corrections and for variable fuselage elevation. The target was attacked using a gun attack, and the independent fuselage aiming capability was used to increase gun solution time on the target. A visual presentation of the strafing pass was presented on a screen before the pilot. The pilot was able to search for and detect targets on the ground. Of the 55 tasks rated, two received responses of uncertainty. These responses are all related to Configuration A and the difficulty in activating switches on the flight and throttle controllers when reclined. The findings are presented in Table 35.

TABLE 35
STRAFING PASS TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION D			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
39A	Position Seat for High G	3	0	1	4	0	0	4	0	0	4	0	0
41A	Select Manual Fuselage Aim Mode	2	1	1	4	0	0	4	0	0	4	0	0

Air-to-Air Combat - Evaluation of the configurations in air-to-air combat for effectiveness is crucial at the 65° back angle, since there is no room for pilot inefficiency due to control/display layout. The air combat segment assumed a disadvantaged start. The pilot received a threat warning on the TEWS system. Appropriate maneuvers were performed to accomplish target identification. Weapon selection was made, and visual combat maneuvers were performed using high acceleration and direct force capabilities to gain the tactical advantage. The target was radar acquired and tracked visually with the aid of the HUD for steering and display of a gun or missile solution. Of the 67 tasks performed, five received negative and questionable responses. Operation of the weapons select and gun fire rate switches proved difficult. The majority of the maybe and no responses were in reference to Configuration A. Table 36 summarizes the findings.

TABLE 36
AIR-TO-AIR COMBAT TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION D			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
16	Position for Attack	3	1	0	4	0	0	4	0	0	4	0	0
50	Select Gun Weapons Mode	3	1	0	4	0	0	3	1	0	2	2	0
51	Monitor Rds Remaining Readout	2	1	1	3	0	1	3	1	0	4	0	0
52	Select Gun Fire Rate High	2	1	1	3	0	1	3	1	0	4	0	0
58	Maneuver for Gun Solution	3	0	1	4	0	0	4	0	0	4	0	0

In-Flight Refueling - In-flight refueling tasks were performed in order to evaluate configuration compatibility with this type mission phase. Following the air combat segment, the aircraft joined up and proceeded to a rendezvous with a tanker aircraft. Navigation tasks were required to locate the tanker, pre-refueling procedures were performed, and refueling configuration tasks were performed by the pilot. Positioning the aircraft for hookup was facilitated by the direct force capabilities which can be used for precision control of the aircraft attitude. Communication between the boom operator and refueling pilot comprised almost a third of the tasks in the segment. Boom hookup was performed, fuel transfer was accomplished, and the boom was disconnected successfully. Post refueling checks were done and the aircraft turned for home base. A visual presentation was used to enhance the simulation of these tasks. Several 35 mm slides of actual fighter aircraft refueling, as seen from the pilot's view, were presented on a screen in front of the design aid. Of the 76 tasks performed during this phase three received questionable responses. One pilot questioned the ability to maintain refueling position using DLF/DSF in Configuration B. The results are summarized in Table 37.

TABLE 37
INFLIGHT REFUELING TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION D			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
49	Set Radar Mode to Standby	4	0	0	4	0	0	3	1	0	3	1	0
53	Maintain Refueling Position with DSF and DLF	4	0	0	3	1	0	4	0	0	4	0	0

Approach/Landing - Following an inbound cruise leg similar to the outbound segment, but with fewer equipment checks, an enroute descent with IFR was made. A TACAN hold was initiated, and penetration was begun following ground control approval. A typical ILS approach and landing were also tasked for the pilot. Of the 158 tasks, 11 received negative or questionable responses. Again, as in takeoff, the primary area of dissent was monitoring gear lights and operating the landing gear control in Configurations D and E. The majority of remaining dissent centered on operating the avionics panel. The results are summarized in Table 38.

TABLE 38
APPROACH/LANDING TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION D			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
11	Select NAV AIDS	4	0	0	4	0	0	3	0	1	3	0	1
12	Select ILS/TCN Steer Mode	4	0	0	4	0	0	3	0	1	3	0	1
13	Select Channel Select	3	0	1	4	0	0	3	0	1	3	0	1
13A	Depress Keys to Designate Chan	3	1	0	4	0	0	3	0	1	3	0	1
13B	Depress Enter	4	0	0	4	0	0	3	0	1	3	0	1
16	Select HSI Course 193	3	1	0	2	2	0	4	0	0	4	0	0
115	Select ILS/NAV Steer Mode	4	0	0	4	0	0	3	1	0	4	0	0
142	Extend Landing Gear	4	0	0	4	0	0	3	1	0	3	0	1
143	Monitor Gear Lights	4	0	0	4	0	0	1	0	3	0	0	4
145	Set Landing Lights Switch to On	3	1	0	4	0	0	1	3	0	2	1	1
165	Brake as Necessary	3	0	1	4	0	0	4	0	0	3	0	1

Post Flight - Post-landing procedures included taxiing from the active runway, basic ground operations, dearmament, engine shutdown, and execution of functional check lists. There were three tasks which received negative or questionable responses during this phase for the 38 tasks performed. The results are summarized in Table 39.

TABLE 39
POSTFLIGHT TASKS
Distribution of Responses /n = 4 Pilots

TASK NO.	TASK DESCRIPTION	CONFIGURATION A			CONFIGURATION B			CONFIGURATION D			CONFIGURATION E		
		YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO	YES	MAYBE	NO
6	Set Landing/Taxi Lights Switch	4	0	0	4	0	0	3	0	1	3	0	1
7	Set Radar Power Control Off	4	0	0	4	0	0	4	0	0	3	0	1
22	Apply Brakes to Stop in Arming Pit	4	0	0	4	0	0	4	0	0	2	0	2

Emergency - Pilot responses to three ejection designs (D-ring, side handle, and face curtain) were collected. For the 20° seat angle, the D-ring was preferred design for all configurations. Side handles were considered

unacceptable by the pilots as the controller mechanization interferes with handle actuation. Configuration A at 20° is the only concept which could use side handles. For the 65° seat angle, the D-ring and the face curtain were about equally acceptable. Combining the ranked preferences of both seat angles, the D-ring was the preferred design if redesigned to improve access in the reclined position.

Paired Comparison Questionnaires

A subjective evaluation of the seat and crew station design aid was conducted to investigate control-display/seat requirements for normal flight and the high acceleration combat mode with the articulating seat concept. A paired comparisons technique was applied for this purpose. This approach forced the test subject to identify his preference for one item over another. Repetition of this process resulted in a preference ranking for all of the design aid items, and provided the required organized procedure for evaluating items by an individual subject. This method is considered a satisfactory way of securing ranked value judgements.

Questionnaires were prepared for the following areas: mission phases, control/displays, cockpit configuration and control/display location. These questionnaires consisted of sets of paired comparisons which were used to derive preference ranking scales. The subject's task was greatly simplified because he was only required to rank the two items being considered for any given comparison. He compared these, passed to another pair, and so on until all items were judged. In all, each subject made 3069 comparisons in the course of this evaluation. To obtain a full set of comparisons each element must be ranked against all others. The total comparisons for any set of items can therefore be calculated by the formula $N(N-1)/2$ where N is equal to the number of items.

Mission Paired Comparison

Each pilot judged which mission phase had the greater importance in terms of impact on the crew station. There were eleven mission segments or 55 paired comparisons to be made by each pilot. Each mission phase appeared ten times. This yielded a total of maximally 40 points for any phase where all pilots selected the same mission phase in all comparisons. The rankings of the pilots were converted to percentages and the results described in Figure 39. The three mission phases judged to have the greatest impact on the crew station were Ejection/Emergency, Air-to-Air Combat, and Approach/Landing. The rank ordered series derived from this evaluation correlated highly with a previous similar evaluation on advanced fighter aircraft ($r_s = .95$ with $P<.01$).

Control/Display Comparison

The pilots judged which control/display group had greater importance in terms of impact on the crew station during the mission and each mission phase. There were 66 paired comparisons to be evaluated for each of the eleven mission phases as well as for the total mission. This yielded 528 measures on each control/display group. Specific equipment related to these groups are identified in Appendix C (Table 86). Figure 40 shows the ranks of the combined scores for the mission. Mission phase scores are provided in Appendix C (Figures 48 to 58).

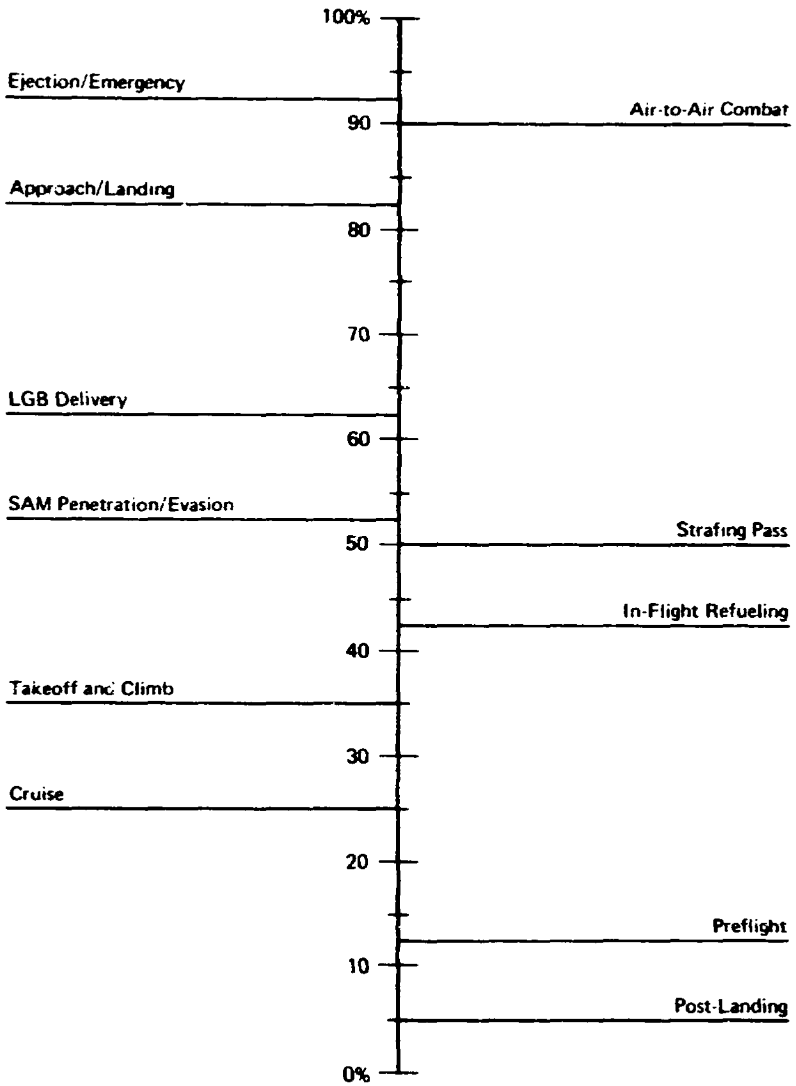


FIGURE 39
MISSION PHASE IMPORTANCE
GP74-0757-36

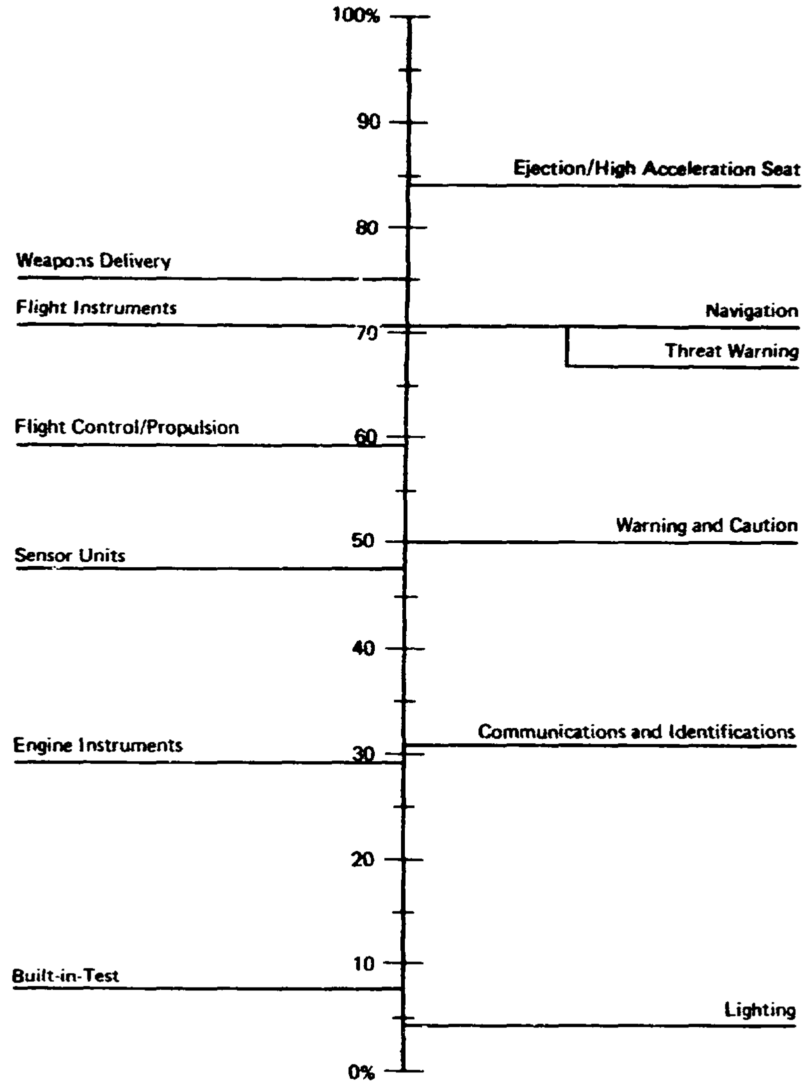


FIGURE 40
CONTROL/DISPLAY IMPORTANCE FOR MISSION
GP74-0757-37

The Spearman rank correlation coefficient test was performed to determine a degree of association or relation between the ordered series based on the overall mission judgements and the ordered series derived by pooling the judgements for the eleven mission segments. The computed r_s was .242; which was not significant at the .05 level. This indicates that the pooled judgements of the 11 mission segments yielded a rank ordered series of controls/displays that did not match the rank ordered series of controls/displays derived from the overall mission judgements.

Cockpit Configuration Comparison - For the total mission and each mission phase, each pilot judged which crew station configuration had the greater potential benefit for a high acceleration cockpit. These rankings are presented in Figures 41 through 47. Configuration E ranked the highest for the total mission and each mission phase (with the exception of cruise - where Configuration B was the slightly higher). Configuration B was superior to A and D for all phases (except ejection). The evaluation was based on 6 pairs of comparisons x 4 pilots x 12 mission phases = 288 measures.

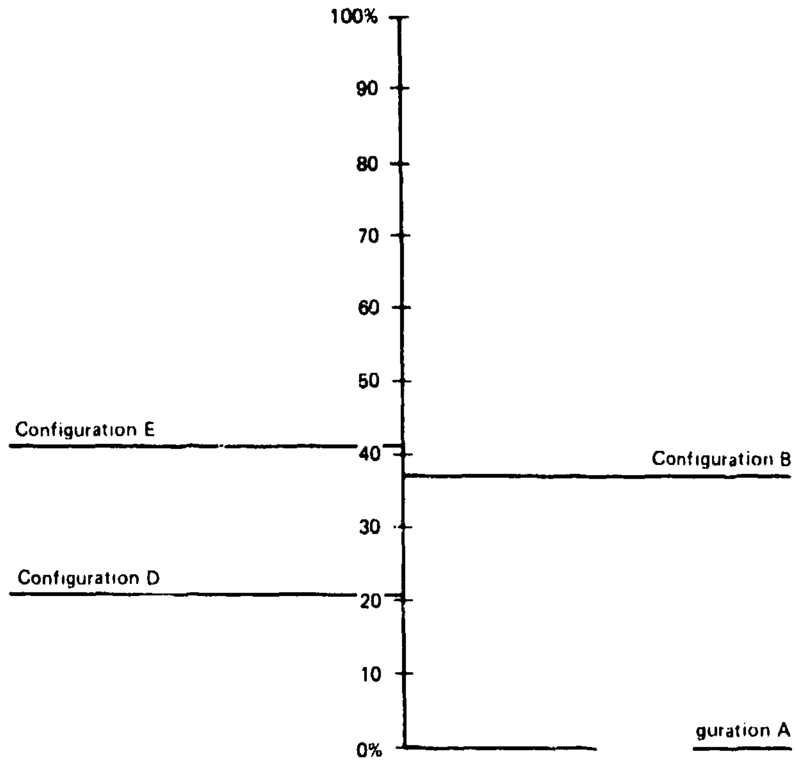


FIGURE 41
COCKPIT CONFIGURATION PREFERENCE FOR TOTAL MISSION

GP74 0757 28

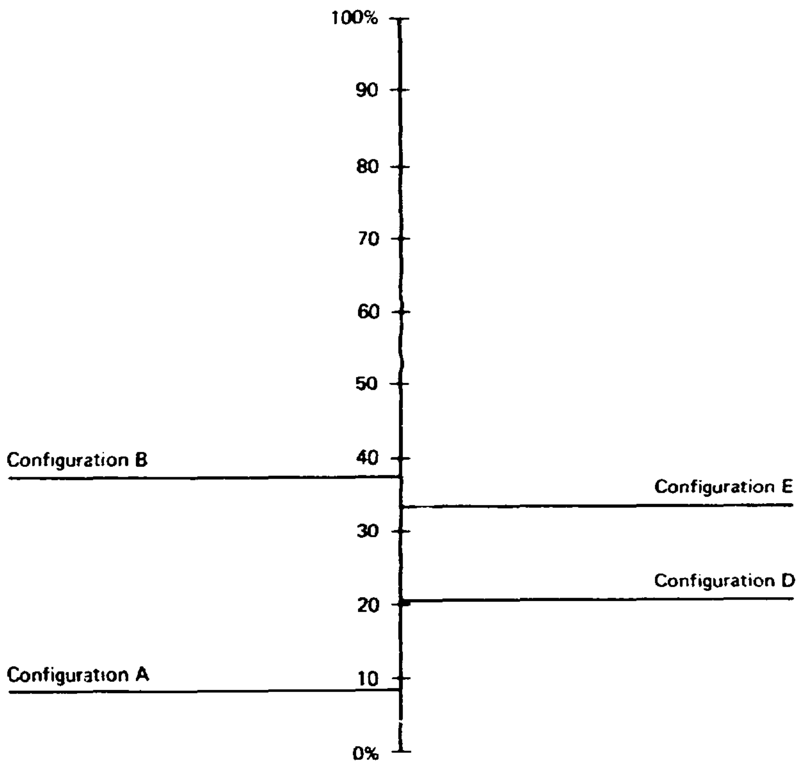


FIGURE 42
COCKPIT CONFIGURATION PREFERENCE FOR CRUISE

GP74-0757-31

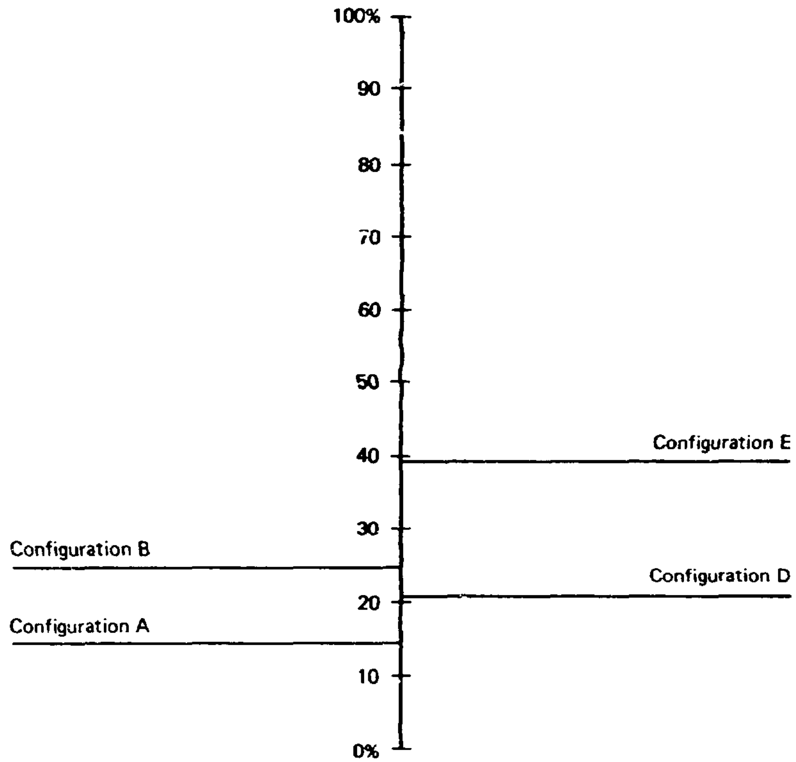


FIGURE 43
COCKPIT CONFIGURATION PREFERENCE FOR PREFLIGHT AND POSTFLIGHT

GP74-0757-30

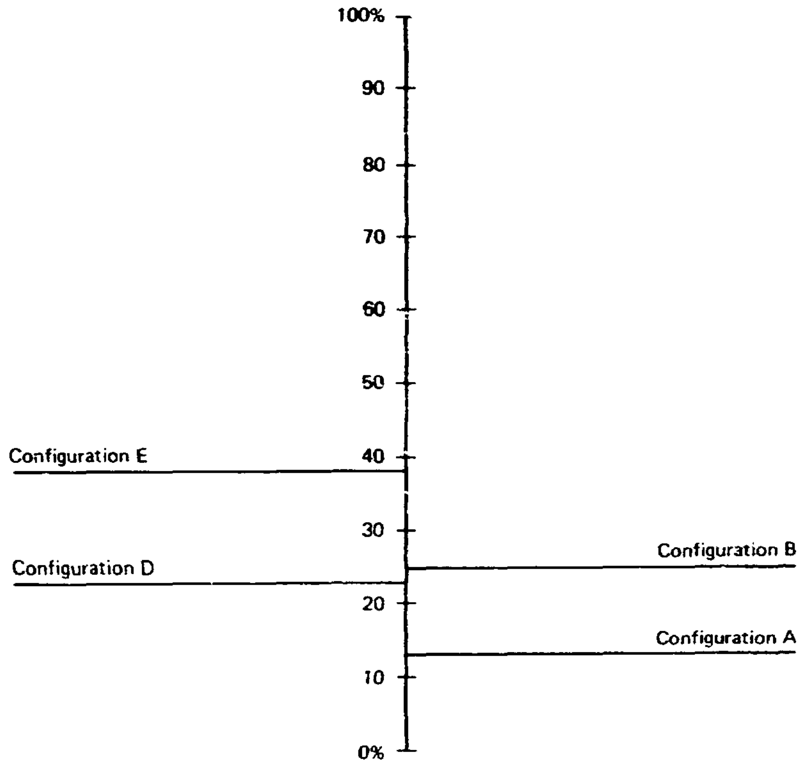


FIGURE 44
COCKPIT CONFIGURATION PREFERENCE FOR TAKEOFF/CLIMB AND APPROACH/LANDING

GP74 0757 29

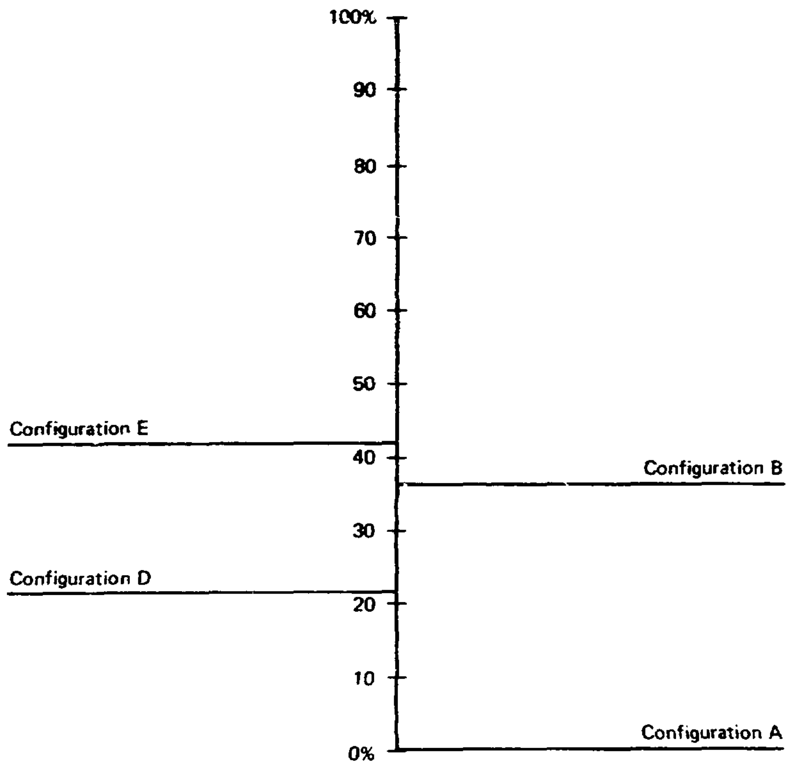


FIGURE 45
COCKPIT CONFIGURATION PREFERENCE FOR SAM PENETRATION/EVASION, LGB DELIVERY, AND STRAFING . ASS

GP74-0757 32

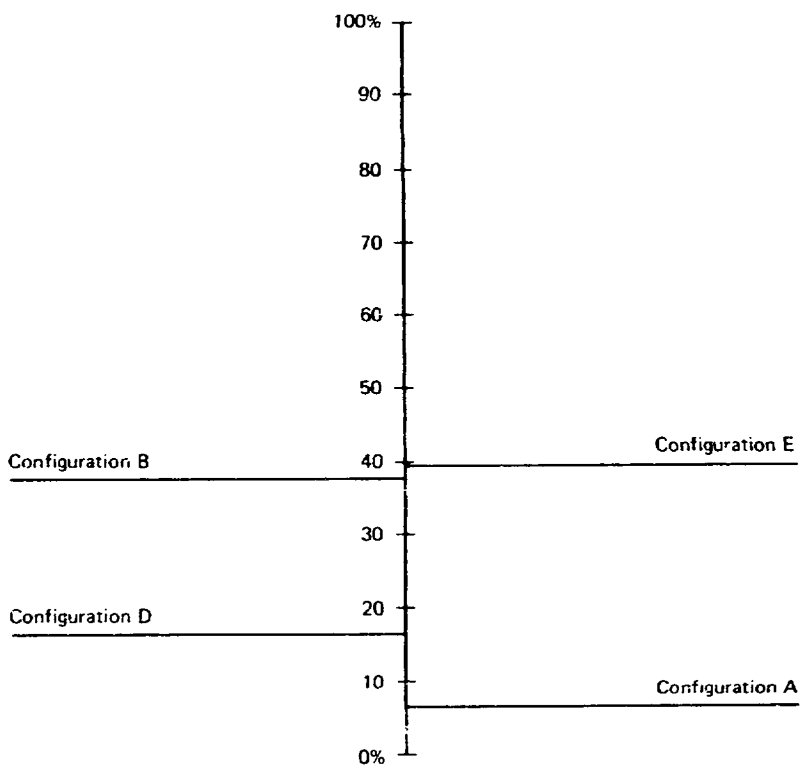


FIGURE 46
COCKPIT CONFIGURATION AIR-TO-AIR COMBAT AND IN-FLIGHT REFUELING

GP74 0757 33

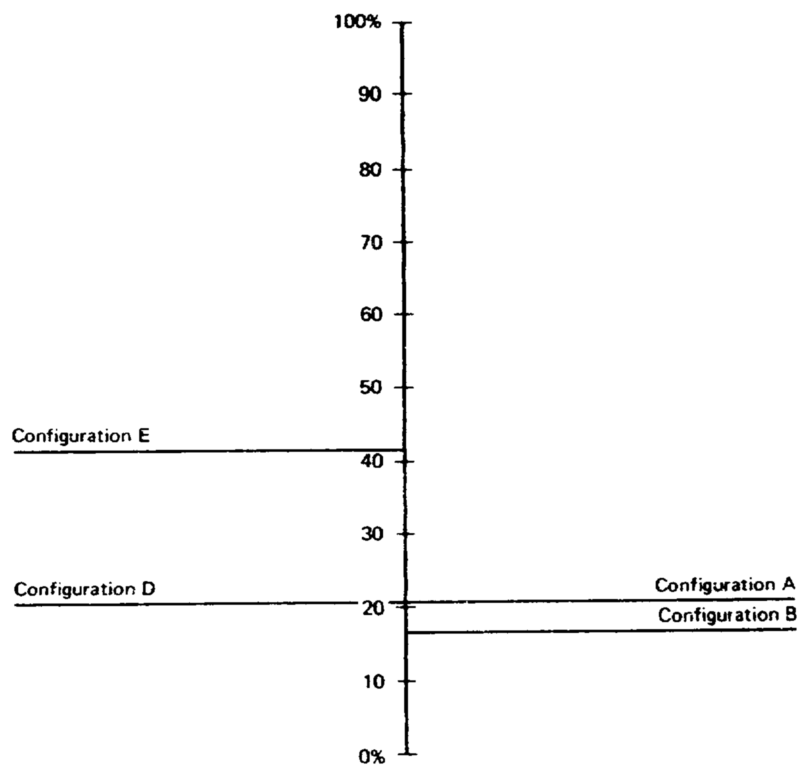


FIGURE 47
COCKPIT CONFIGURATION PREFERENCE FOR EJECTION

GP74-0757-34

Control/Display Location Comparisons - Each control/display location (or design) was judged by each pilot for the greater potential benefit for a high acceleration cockpit. There were 54 control/display variables, each of which had two to four choices. This yielded 95 paired comparisons x 4 pilots for 380 measures per mission segment. Forty of the 54 control/display variables yielded responses which indicated a preference for a specific control/display location or configuration.

A summary of the findings is tabulated in Table 87 in Appendix C.

Pilot Interview Questionnaire

The primary purpose of the pilot interview questionnaire was to collect comments related to controller location and design. Other factors relating to the comfort and utility of the high acceleration cockpit concept were included in the questionnaire to provide an overall assessment of pilot acceptance.

Pilot opinion on the following factors were requested for the various controller location configurations in both the upright and reclined seat position:

- Controller location preference
- Leg space and seat comfort
- Seat position
- Secondary control/display location and access
- Flight and throttle controller grip design
- Internal clearances
- Head and arm support
- External and internal vision
- Rudder pedal access

Specific Pilot Comments

The following paragraphs present the major pilot comments relative to the above areas.

Controller Location - The following statements relate to the pilots' preference for both the upright (20°) and reclined (65°) seat positions.

- (@ 20°) "Overall this one (Configuration B) would be a very good, very flexible controller arrangement. However, I feel equally strong about Configuration E for a different reason. Basically, in the reclined position the arm rest mounted controls (Configuration B) and even in the upright position restrict your movement. It's difficult to maneuver around them to get to the switches. As far as I am concerned I would rather have the access with Configuration E. --- I am not sure the controller location is that critical, however, mobility is critical. I like E better than B."

  (@ 65°) "Configuration E opens your field of view and gives you more access to some of these switches up on the instrument panel which

could be critical in a high load factor regime - certainly the emergency jettison."

- (@ 20°) "I like this overlap here (Configuration B), but I would like to try it out on a simulator because I am not sure what kind of control problems you would encounter. Some of the things I am thinking about is that normally the stick is like that, it's either fore, aft or sideways but when you cant it in like that for the pitch movement you pull sideways. I would like to try it in a simulator. My second choice would be Configuration E."

  (@ 65°) "I still prefer Configuration B. This may all change, if I dynamically had a chance to compare Configuration B as opposed to E I may want Configuration E."

- (@ 20°) "I prefer Configuration E because in the upright position the throttles and flight controller are comfortable and one could fly long missions and formation with low pilot workload. One could also fly without any discomfort in the upright position. One of the drawbacks to Configuration B are that the throttle and flight controller are too close to my chest in the upright position."

  (@ 65°) "I prefer Configuration E. The reasons I stated in the upright position apply to the reclined position."

- (@ 20°) "In this seat position I prefer Configuration D or E. The only thing wrong with A is that they are not adjustable. My last choice would be B. The arm rests block my view and access to some of the console controls."

  (@ 65°) "I would prefer Configuration B because of the arm support plus the controllers can be located closer to centerline; it's a more natural and comfortable feeling. Configuration E is my second choice."

Leg Space and Seat Comfort - All pilots expressed the opinion that the leg space was adequate and the seat comfortable in both the upright and reclined positions. A typical quote is, "Leg space is adequate and the seat is comfortable. I have taken a little nap before."

Seat Position - Comments in response to reclining the seat in situations other than during high load factor engagements were:

- "Yes for comfort"

- "Yes definitely so -- I think that any time I am in enemy territory I would probably put it up and leave it up until I got out of the high threat environment."

- "It would help for long range cruise - the butt gets awful tired."

- "Yes I would. I think I would probably use reclined seat positions just to reduce fatigue."

Control/Display Location - Opinions related to relocating various secondary controls and displays included:

- "I think you need dedicated comm volume controls. -- I like the landing gear control where it is located (in Configuration E), I don't see any reason for having it up here." (Pilot in Configuration B.)

- "The landing/taxi light control is almost unusable, it could be relocated outboard of the throttles or under the sill. If there were some way to get the integrated avionics panel on the left instrument panel, as in some of the other configurations I have seen, and have enough room so that you don't interfere with the throttle when you operate it, I would prefer that location." (Pilot in Configuration E.)

- "The landing gear control should be mounted higher. Right now the landing/taxi light switch is almost unaccessible." (Pilot in Configuration E.)

Flight Controller - The pilots were requested to comment if the integration of the trim function on the integrated flight controller presented any difficulties.

- "Not knowing all the ramifications of a fly-by-wire system, I would say no. What I might need would be a light that tells me I am in the trim mode."

- "I think it might, I prefer a limited displacement stick and I think I would prefer a discrete trim button."

- "My first gut feel was that I wanted a dedicated trim button but since flying the mission scenarios and thinking on how much you would use direct lift and side force, I think it's a workable configuration. It's more workload on the pilot but with training I think he would get used to it. The direct lift/side force and fuselage aiming should be dedicated controls."

- "I like to have trim all the time without selecting it from some other mode. I would like to see two separate isometrics for the direct lift/direct side force and fuselage aiming."

Throttle Controller - The following series of comments relate to the location of switches on the canted throttle as compared to the baseline design. For the weapons mode select switch comments ranged from preference for the baseline design to "Machs-nichts." Similar comments were obtained for the other switches including the rudder trim/weapons uncage, IFF, speedbrake/modulated drag, ECM, radar designate, and radar elevation. Specific comments were obtained from all four pilots on the radar designate isometric which indicate the desirability of locating this switch for index finger or middle finger operation as compared to ring finger operation. Universally the pilots disliked the comm button location on the canted throttles. During the mission scenarios they considered use of this control as a "maybe" function. A more

favorable location was noted for the comm button on the canted throttle directly below the thumb recess. The pilots stated that if the switch were located there the "maybe" responses would certainly change to "yes" responses.

Comments relating to the general shape and feel of the two grip designs were:

- "I like the canted ones better."

- "I like this canted throttle here, it feels more comfortable. If we could move some of these switches up to where you could reach them a little easier, I think it would be the better design."

- "I prefer the canted throttle. It is more comfortable. It fits the hand real well."

- "The canted throttles have a comfortable and natural feeling."

Leg/Controller/Sill Clearance - Pilots comments on the leg/controller/sill clearance for Configurations D and E where the controller is located between the seat and the sill were:

- "There is not enough clearance in the case of D; it was adequate in E."

- "Yes, there is enough clearance, the only problem is with the throttle. If I kept my hand on the throttle and actuated the seat I would probably cut my little finger off."

- "I like it the way it is. In big cockpits I feel like I am sitting in a room instead of sitting in a airplane. It's just a comfortable feeling more or less than anything else. With the flight controller there is plenty of clearance even with gloves. With the throttle the clearance with the canopy rail is minimal. For more room I would prefer that you locally scallop the sill."

Arm Rests - Pilot comments on if they need arm rests as presented in Configuration E in the reclined position and the need for arm rests in the upright position were:

Reclined

- "I don't really think you need arm rests. For the short duration of G we are talking about."

- "I think I would rather not have them because they would be in the way."

- "If the arm rests would flip up when you lift your arm so that you could get to the panels easy they would be improved. They felt comfortable."

- "I would like to see them larger and I would like to see them spring loaded."

Upright

- "No, and the reason for that is that we don't have arm rests now and we get along fine."

- "That's tough to answer - I would like to try it in the simulation and see."

- "No, they are not required."

- "Yes, I think you are going to need them, there is nothing here to steady my hand except the hand controller (pilot in Configuration E). I guess I compare it to shooting a pistol, I think you need a rest, I could do a better job. With a conventional stick I use my knee as an arm rest. For final corrections I just move my knee because I can move it more precise than I can my hand. The throttle is not that critical."

Head Rest - Comments on the head rest in terms of size and support in the reclined position were:

- "If it could be made smaller I would like it, but the overriding factor here is that under high G you aren't going to be moving your head - that's true whether you're upright or reclined it really doesn't make any difference."

- "It's adequate - perhaps it could even be made a little bit smaller. It is the limiting factor in how far you can see behind the tail. As long as you have a bubble canopy and can see to 6 o'clock, one should make the head rest as small as possible."

- "It's comfortable, if I can move my head when I am pulling 6 or 7 G's it is OK."

Similar comments were obtained in the upright seat position.

External Visibility - The pilots commented on whether the reclining seat/head rest enhances or degrades external visibility.

- "You must trade off reduced mobility (of the head when reclined) for the increased upward visibility that you get so I think it's about the same."

- "It doesn't degrade it. Under high G loading it might be kind of hard to turn your head and check 6 o'clock."

- "It improves it. You can really crank your neck around and force back on the head rest."

- "It doesn't degrade it, it's a question of if it enhances it. My head hasn't moved that much. Actually I am looking in a better area. You're looking about where you want to be looking."

All of the pilots expressed essentially the same opinions on the following items:

- <u>Rudder Pedals</u> - The rudder pedals need to be scheduled to change fore and aft position as a function of seat back angle.

- <u>Instrument Panel Visibility and Access</u> - For air-to-air combat the visibility and access of the main instrument panel was adequate. One pilot expressed an opinion to the contrary for Configuration B which was, "No, because the controllers obscure a significant portion. That portion happens to be the master arm switch for one. It would be adequate in Configuration E."

- <u>Consoles</u> - The pilots felt their loss of contact and visibility of the right and left consoles would not hinder their performance in air combat maneuvering.

- <u>Reclining Action</u> - With regards to the reclining action of the seat, the pilots felt that this action should be pilot actuated.

- <u>Emergency Warning Panel</u> - The emergency warning panel was considered adequate if supplemented by a readout on MSD-1 or the HUD of the more critical parameters.

- <u>Landing</u> - All of the pilots felt that there would be no problem landing the aircraft with the seat reclined.

<u>High Acceleration Cockpit Concept</u> - Pilot comments on the practicability of the cockpit concept were:

- "I don't really have any doubts as to the practicability, I think it's a necessary improvement, this appears to be the most logical way, if not the only way."

- "I don't have any doubts - based on centrifuge data it's a workable concept."

- "It's super-super."

- "No, I don't have any doubts about it, I would like to see it built. It would increase our air-to-air capability."

Test Critique

Final group interviews were held to elicit pilots' opinions on the test methodology and test procedures and to establish potential R&D goals. Generally, the pilots did not feel that evaluating four configurations taxed their ability to make a valid evaluation. However, the pilots stated that there were brief periods of confusion in retaining separate identity of the configurations during the test sessions. This confusion was alleviated by reference to control/display layouts and discussions with the test conductors. During the test critique the various controller configurations were discussed to insure the pilot preferences corresponded with their replies on the questionnaires. Some objections were made about the subjective portion of the test program. It was felt that there were too many questions to answer and too many paired comparisons to make. It appeared at times to some of the pilots that a question asking for certain information had either been repeated in another form or its relevance to the test objectives was not apparent. Recommendations were made to abbreviate and/or consolidate the subjective survey but still provide complete study coverage and to make the objective of the questionnaire survey clear to the pilots during the prebriefing session.

The mission scenario approach was well accepted. It projected the pilot into a mission performing context; thus, his responses were inclined to be more mission-oriented. Recommendations were made to further enhance the realism of the mission scenario by the use of additional video material, particularly of the display symbology on the HUD and MSDs in their various functional modes.

The pilots felt that some level of simulation would have yielded more direct tasking with the controllers and greater assurance of unequivocal acceptance or non-acceptance of specific design characteristics, and would have minimized pilot statements recommending design comparisons under dynamic simulation. Future studies similar to this one should consider selective simulation.

Finally, it was the consensus of the pilots that the three orientation sessions -- prebriefing, display briefing and cockpit drawing review were required. They felt that sufficient pretest knowledge of the system was essential in order to make valid responses during the actual testing.

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SECTION VII

PRINCIPAL PROGRAM ISSUES

All program objectives were satisfied. A minimum size high acceleration cockpit design aid was used to evaluate four flight and throttle controller concepts. The preferred controller locations are specific to this small cockpit and should not be applied directly to a larger cockpit. Additional geometric impact due to personal equipment was found equivalent for all configurations, as noted by use of pilot supplied equipment (helmet, mask, G-suit). Combat survival gear was not included here because of the specialized nature of its design due to configuration deployment area. When evaluated, it was felt that this interface also would be consistent for all configurations. Pilot self adjust of the restraint system via personal habits provided a realistic basis for comparative reach evaluations Removal of basic cockpit geometric constraints would present a less demanding environment in terms of controller integration. The basic controller location concepts would however remain valid. The design aid allowed evaluation of many controller options and control/display integration concepts. The design aid provided a measure of flight task utility for the alternative concepts. Controller modeling, with formal test and evaluation phases, allowed identification of pertinent research and development goals. Recommendations are categorized according to controller development task and related cockpit tasks leading to near term demonstration of the high acceleration cockpit approach.

HIGH ACCELERATION COCKPIT R&D PRIORITIES

Development goals are divided into those directly related to controllers and their location/mechanization and those related to other aspects of the high acceleration cockpit. Meaningful R&D can be performed for: (1) systems definition and engineering development; (2) human engineering interfaces in restraint and support systems; and (3) additional understanding of impact of improved G tolerance on pilot physiological performance.

Controller Locations

A primary area, in which additional attention should be focused, is determining actual pilot performance for the two primary controller locations (longitudinal and over-the-lap) through part task simulation. The part task simulation can be accomplished to provide basic concept screening in a fixed base design aid with alternate controller locations, similar to other recent studies, Reference (11). It is also appropriate to assess the basic grip design and mechanization in this part task simulation. Development issues include the degree of stick motion, gain schedules to provide adequate pilot cues, and the effects of integrating functions on the flight control grip.

Subsequent to the static part task simulation the most promising designs should be investigated in a dynamic environment (centrifuge or motion base simulator). This simulation could be fixed tracking tasks followed ideally by manned interactive air combat simulation. The fixed tracking tasks would

also enable assessment of the interactions between controller utility and arm support designs. Although the arm supports assessed in this study appeared to be adequate, the need for arm support in the reclined position under sustained maneuvering loads cannot be adequately assessed in static simulation.

In this study it became very evident that the basic design aid geometric constraints imposed on controller location/mechanization concepts prohibited the use of numerous otherwise promising designs. For potential near term demonstration it is appropriate to assess the integration aspects of the flight and throttle controllers in contemporary cockpits. Immediate attention should be given to definition of a minimum impact modification of an existing cockpit, flight control, and throttle control system for flight demonstration purposes. Suggested parallel efforts for both demonstration purposes and future systems are presented in subsequent paragraphs.

Ejection System

Highest priority should be given to engineering definition of an articulating ejection seat. While earliest attention should be given to definition of a minimum impact modification of an existing system for demonstration purposes, the reclined position suggests attractive ejection alternatives (transverse to spinal axis) for advanced systems. Parallel anthropometric and physiological efforts should enable definition of an "optimum" reclined position, leading to a specific seat design shape. A prototype inflatable air bag configuration, recently developed by the Flight Dynamics Laboratory, shows potential as a near term demonstration concept. Both the inflatable concept and the shoulder pivot concept, described in Reference (6), require concentrated engineering development before either can be used for demonstration or operation purposes.

Pilot Support/Restraint

Design provisions for limb and head support in addition to arm rests should be investigated with specific attention toward simple, reliable supports which do not impact the normal flight pilot/cockpit interfaces. Parallel centrifuge work can yield meaningful evaluation of candidate designs and provide guidelines for specific limb position and mobility. Investigation of head support concepts, integral with the seat, should be directed toward providing reclined head mobility (e.g., helmet rollers). It is anticipated that developments in this area provide an initial step toward definition of reclined sight system analogous to current helmet sight/display work. The natural head support offered by the head rest for the reclined positions studies to date offers an opportunity to alleviate the current disadvantage associated with flight helmets (i.e., weight).

Controls and Displays

Substantial design enhancement can be provided by continued research and development in the advanced control/display area, as typified by the concepts applied in this program. The use of an advanced HUD with flight information "call-up" and multi-sensor CRT displays with optional display modes offer considerable potential for cockpit size, weight and volume reduction. Advanced

tape displays, digital readouts, and packaging concepts can provide considerable design flexibility, especially in the primary display area. One particular innovation introduced to represent a control/display technology representative of a 1980 IOC design is the integrated avionics panel. The reduction in required cockpit panel area can provide substantial payoffs. Use of an integrated panel such as this facilitates clustering of all control (action-switching) functions into the left side. This allows the right hand to be dedicated to stick and stick grip functions, with displays clustered into the right cockpit side. Typical development needs (in addition to hardware and software definition) include selection of appropriate control clusters for integration and refinement of switch type, position, and location for optional cockpit use.

Additional control/display developments which can provide considerable enhancement include definition of a light intensity and symbol code compatible with the secondary display-recessed panel concept.

Survival Gear - Current combat survival gear should be investigated with the goal to reducing bulk and weight or, ideally, relocated to an aircraft mounted location. Although combat survival gear was not employed during the testing, due to the specialized nature of its design as a function of aircraft deployment, it is recognized that chest worn gear would have consistently degraded internal cockpit visual capability. An additional drawback of chest worn gear, germane to both fixed and articulating seat concepts is the loading imposed upon the pilot during high load factor maneuvers. Efforts to reduce both the size and weight would therefore benefit the pilots of both current and proposed fighter aircraft.

RECOMMENDED ACTION

Aggressive R&D activity is recommended in each of the following areas to provide for near term high acceleration cockpit demonstration and future system design enhancement:

- Primary flight and throttle controller part task and dynamic simulation evaluating location, grip design, functional integration, stick motion, gain schedules, and arm support interactions

- Design definition and engineering development of a high acceleration cockpit compatible with an existing high performance fighter to provide for near term demonstration of the high acceleration cockpit concept

- Engineering development of an ejection seat compatible with high acceleration cockpit concepts (including guidelines for qualification of near term modification approaches)

- Investigation of anthropometric and physiological characteristics of reclined positions (including forward head support) compatible with high acceleration cockpit concepts to identify an optimal position, need for secondary supports, and influences of reduced mobility from this position on controller gain schedules

- Integration of personal equipment to accommodate support under elevated load factors and compatibility with seat articulation

- Investigation of alternatives and adjuncts to helmet sight/display concept based upon the new freedoms offered by the use of head support in the reclined position.

Remaining R&D activities which should enhance advanced cockpit development for all future fighters include:

- Continued development of advanced HUD and multi-sensor display systems

- Development of a simplified integrated avionics capability providing for maximum pilot familiarity and convenient cockpit use

- Continued research into cockpit lighting standards, visual, aural, and sensory cues

- Development of combat survival gear with the goal of reduced weight and bulk.

It is further recommended that the structured task/static simulation techniques used in this program for initial screening of controller location concepts be adapted early in the design phase for future fighter cockpit definition. The relative simplicity, with reduced commitment and risk, associated with the design aid technique allows evaluation of many alternative concepts, while providing an early understanding and insight into necessary and meaningful research and development goals.

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APPENDIX A

TASK PERFORMANCE MULTIPLE RANGE TESTS

Task performance times were collected on thirty-three tasks for the purpose of effecting a comparative evaluation of the controller-throttle locations and the overall cockpit geometry associated with each location. A stratified sampling technique was applied to select tasks that would provide an assessment of reach adequacy to the left console, right console, and main instrument panel. Eleven tasks were not performed for some of the configurations because the location of the controls and displays for these tasks could not be reached by the pilots. Consequently the remaining 22 tasks were ordered to form a 4x8x22 analysis of variance.

TASK PERFORMANCE

The results of the 4x8x22 ANOVA are summarized in Section VI. This appendix contains the separate Duncan's multiple range tests of the statistically significant tasks. These tests are depicted in Tables 40 through 55.

A summary of statistically significant tasks is:

- o Emergency Speed Brake - Task 2
- o Auxiliary Power - Task 3
- o TACAN BIT - Task 4
- o UHF Comm Chan - Task 5
- o Landing Lights - Task 8
- o Landing Gear - Task 9
- o Landing Lights/Landing Gear/Push to Jettison - Task 10
- o Jammer Pushbutton - Task 11
- o Master Arm - Task 13
- o MSD 1 Radar Mode - Task 16
- o Emergency Vent - Task 17
- o Temperature Panel Air Source - Off to Both - Task 18
- o Interior Lights - Off to Bright - Task 19

o Exterior Lights - Off to Dim - Task 2

o Decoy Chaff Units - Burst 3 to C - Task 21

o Decoy Flares Interval 8 to 12 - Task 22

The net result of the findings in Tables 40 to 55 indicated that Configuration B at 65° seat angle showed increased task time for more tasks tested than other configurations. Configurations D and E were about the same, while A was the lowest.

TABLE 40
TASK 2 COMPARISON OF MEAN TIMES
Emergency Speed Brake
Seconds

Config.		(1) A20	(2) B20	(3) E20	(4) D20	(5) D65	(6) B65	(7) E65	(8) A65	Shortest Significant Range	
	Mean	2.15	2.28	2.30	2.35	2.48	2.78	2.80	2.90	.05**	.01*
(1)	2.15	-	.13	.15	.20	.33	.63**	.65**	.75**	R_2=0.528	0.716
(2)	2.28		-	.02	.07	.20	.50	.52	.62**	R_3=0.555	0.747
(3)	2.30			-	.05	.18	.48	.50	.60**	R_4=0.572	0.767
(4)	2.35				-	.13	.43	.45	.55	R_5=0.584	0.782
(5)	2.48					-	.30	.32	.42	R_6=0.592	0.794
(6)	2.78						-	.02	.12	R_7=0.600	0.803
(7)	2.80							-	.10	R_8=0.605	0.811

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 41
TASK 3 COMPARISON OF MEAN TIMES
Auxiliary Power
Seconds

Config.		(1) D20	(2) E20	(3) A20	(4) B65	(5) B20	(6) E65	(7) D65	(8) A65	Shortest Significant Range	
	Mean	2.38	2.43	2.53	2.60	2.73	2.75	3.32	3.43	.05**	.01*
(1)	2.38	-	.05	.15	.22	.35	.37	.94**	1.05**	R_2=0.768	1.040
(2)	2.43		-	.10	.17	.30	.32	.89**	1.00**	R_3=0.806	1.085
(3)	2.53			-	.07	.20	.22	.79	.90**	R_4=0.831	1.115
(4)	2.60				-	.13	.15	.72	.83**	R_5=0.848	1.137
(5)	2.73					-	.02	.59	.70	R_6=0.862	1.154
(6)	2.75						-	.57	.68	R_7=0.872	1.167
(7)	3.32							-	.11	R_8=0.880	1.178

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 42
TASK 4 COMPARISON OF MEAN TIMES
TACAN BIT
Seconds

Config.		(1) B20	(2) A20	(3) E20	(4) D20	(5) A65	(6) E65	(7) D65	(8) B65	Shortest Significant Range	
	Mean	2.73	2.98	2.98	3.38	3.60	3.83	4.08	4.10	.05**	.01*
(1)	2.73	-	.25	.25	.65	.87	1.10**	1.35**	1.37*	R_2=0.867	1.175
(2)	2.98		-	.00	.40	.62	.85	1.10**	1.12**	R_3=0.911	1.225
(3)	2.98			-	.40	.62	.85	1.10**	1.12**	R_4=0.939	1.259
(4)	3.38				-	.22	.45	.70	.72	R_5=0.958	1.284
(5)	3.60					-	.23	.48	.50	R_6=0.973	1.303
(6)	3.83						-	.25	.27	R_7=0.985	1.318
(7)	4.08							-	.02	R_8=0.993	1.331

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 43
TASK 5 COMPARISON OF MEAN TIMES
UHF Communication Channel
Seconds

Config.		(1) B20	(2) E20	(3) D20	(4) A65	(5) A20	(6) E65	(7) B65	(8) D65	Shortest Significant Range	
	Mean	2.40	2.43	2.63	2.88	3.20	3.25	3.68	3.88	.05**	.01*
(1)	2.40	-	.03	.23	.40	.80	.85	1.28**	1.48**	R_2=1.057	1.432
(2)	2.43		-	.20	.45	.77	.82	1.25**	1.45**	R_3=1.110	1.494
(3)	2.63			-	.25	.57	.62	1.05	1.25**	R_4=1.144	1.535
(4)	2.88				-	.32	.37	.80	1.00	R_5=1.168	1.565
(5)	3.20					-	.05	.48	.68	R_6=1.186	1.588
(6)	3.25						-	.43	.63	R_7=1.200	1.6062
(7)	3.68							-	.20	R_8=1.211	1.622

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 44
TASK 8 COMPARISON OF MEAN TIMES
Landing Lights
Seconds

Config.		(1) B20	(2) A65	(3) A20	(4) B65	(5) E20	(6) D20	(7) E65	(8) D65	Shortest Significant Range	
	Mean	2.20	2.23	2.25	2.73	2.80	3.25	3.45	3.53	.05**	.01*
(1)	2.20	-	.03	.05	.53	.60	1.05**	1.25*	1.33*	R_2=0.744	1.009
(2)	2.23		-	.02	.50	.57	1.02**	1.22*	1.30*	R_3=0.782	1.052
(3)	2.25			-	.48	.55	1.00**	1.20*	1.28*	R_4=0.806	1.081
(4)	2.73				-	.07	.52	.72	.80	R_5=0.823	1.102
(5)	2.80					-	.45	.65	.73	R_6=0.835	1.118
(6)	3.25						-	.20	.28	R_7=0.845	1.131
(7)	3.45							-	.08	R_8=0.853	1.142

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 45
TASK 9 COMPARISON OF MEAN TIMES
Landing Gear
Seconds

Config.	Mean	(1) B20 1.73	(2) B65 1.83	(3) E20 1.93	(4) A65 2.18	(5) D20 2.40	(6) A20 2.73	(7) E65 2.75	(8) D65 3.55	Shortest Significant Range .05**	.01*
(1)	1.73	-	.10	.20	.45	.67	1.00	1.02	1.82*	R_2=1.115	1.511
(2)	1.83		-	.10	.35	.57	.90	.92	1.72*	R_3=1.171	1.576
(3)	1.93			-	.25	.47	.80	.82	1.62**	R_4=1.207	1.619
(4)	2.18				-	.22	.55	.35	1.37**	R_5=1.232	1.651
(5)	2.40					-	.33	.35	1.15	R_6=1.251	1.675
(6)	2.73						-	.02	.82	R_7=1.266	1.695
(7)	2.75							-	.80	R_8=1.278	1.711

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 46
TASK 10 COMPARISON OF MEAN TIMES
Landing Lights/Landing Gear/Push to Jettison
Seconds

Config.	Mean	(1) B20 3.40	(2) A20 3.40	(3) A65 4.08	(4) E20 4.33	(5) D65 4.55	(6) B65 4.68	(7) D20 4.78	(8) E65 6.00	Shortest Significant Range .05**	.01*
(1)	3.40	-	.00	.68	.93	1.15	1.28	1.38	2.60*	R_2=1.258	1.705
(2)	3.40		-	.68	.93	1.15	1.28	1.38	2.60*	R_3=1.321	1.778
(3)	4.08			-	.25	.42	.60	.70	1.92*	R_4=1.362	1.827
(4)	4.33				-	.22	.35	.45	1.67**	R_5=1.390	1.863
(5)	4.55					-	.13	.23	1.45**	R_6=1.412	1.890
(6)	4.68						-	.10	1.32	R_7=1.429	1.912
(7)	4.78							-	1.22	R_8=1.442	1.931

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 47
TASK 11 COMPARISON OF MEAN TIMES
Jammer Push Button
Seconds

Config.		(1) B20	(2) A20	(3) E20	(4) E65	(5) A65	(6) D20	(7) D65	(8) B65	Shortest Significant Range .05**	.01*
	Mean	1.73	1.93	2.03	2.20	2.20	2.25	2.33	2.48		
(1)	1.73	-	.20	.30	.47	.47	.52	0.60	0.75**	R_2=0.575	0.779
(2)	1.93		-	.10	.27	.27	.32	.40	0.55	R_3=0.604	0.813
(3)	2.03			-	.17	.17	.22	.30	.45	R_4=0.623	0.835
(4)	2.20				-	.00	.05	.13	.28	R_5=0.636	0.851
(5)	2.20					-	.05	.13	.28	R_6=0.645	0.864
(6)	2.25						-	.08	.23	R_7=0.653	0.874
(7)	2.33							-	.15	R_8=0.659	0.883

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 48
TASK 13 COMPARISON OF MEAN TIMES
Master Arm
Seconds

Config.		(1) B20	(2) E20	(3) D20	(4) E65	(5) A20	(6) A65	(7) D65	(8) B65	Shortest Significant Range .05**	.01*
	Mean	1.70	1.75	1.80	1.90	1.95	1.98	2.13	2.40		
(1)	1.70	-	.05	.10	.20	.25	.28	0.43	0.70*	R_2=0.452	0.613
(2)	1.75		-	.05	.15	.20	.23	.38	0.65**	R_3=0.475	0.640
(3)	1.80			-	.10	.15	.18	.33	0.60**	R_4=0.490	0.657
(4)	1.90				-	.05	.08	.23	0.50**	R_5=0.500	0.670
(5)	1.95					-	.03	.18	0.45	R_6=0.508	0.680
(6)	1.98						-	.15	.42	R_7=0.514	0.688
(7)	2.13							-	.27	R_8=0.518	0.694

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 49
TASK 16 COMPARISON OF MEAN TIMES
MSD 1 Radar Mode
Seconds

Config.		(1) E20	(2) B20	(3) A20	(4) E65	(5) D20	(6) A65	(7) B65	(8) D65	Shortest Significant Range	
	Mean	1.73	1.78	2.13	2.15	2.28	2.38	2.53	2.65	.05**	.01*
(1)	1.73	-	.05	.40	.42	.55	.65	0.80	0.92**	R_2=0.768	1.040
(2)	1.78		-	.35	.37	.50	.60	.75	0.87**	R_3=0.806	1.085
(3)	2.13			-	.02	.15	.25	.40	0.52	R_4=0.831	1.115
(4)	2.15				-	.13	.23	.38	.50	R_5=0.848	1.137
(5)	2.28					-	.10	.25	.37	R_6=0.862	1.154
(6)	2.38						-	.15	.27	R_7=0.872	1.167
(7)	2.53							-	.12	R_8=0.830	1.178

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 50
TASK 17 COMPARISON OF MEAN TIMES
Emergency Ventilation
Seconds

Config.		(1) B20	(2) A65	(3) E20	(4) A20	(5) D20	(6) B65	(7) D65	(8) E65	Shortest Significant Range	
	Mean	2.00	2.15	2.18	2.25	2.40	3.03	3.08	3.23	.05**	.01*
(1)	2.00	-	.15	.18	.25	0.40	1.03**	1.08**	1.23*	R_2=0.739	1.000
(2)	2.15		-	.03	.10	.25	0.88**	0.93**	1.08**	R_3=0.776	1.044
(3)	2.18			-	.07	.22	0.85**	0.90**	1.05**	R_4=0.799	1.072
(4)	2.25				-	.15	0.78**	0.83**	0.98**	R_5=0.816	1.093
(5)	2.40					-	0.63	0.68	0.83**	R_6=0.829	1.110
(6)	3.03						-	.05	0.20	R_7=0.839	1.123
(7)	3.08							-	.15	R_8=0.846	1.133

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 51
TASK 18 COMPARISON OF MEAN TIMES
Temperature Panel Air Source - Off to Both
Seconds

Config.		(1) A20	(2) E20	(3) B20	(4) D20	(5) A65	(6) D65	(7) E65	(8) B65	Shortest Significant Range	
	Mean	2.68	2.85	2.95	3.15	3.90	3.98	5.10	5.75	.05**	.01*
(1)	2.68	-	.17	.27	.47	1.22	1.30	2.42*	3.07*	R_2=1.530	2.073
(2)	2.85		-	.10	.30	1.05	1.13	2.25**	2.90*	R_3=1.607	2.162
(3)	2.95			-	.20	.95	1.03	2.15**	2.80*	R_4=1.656	2.221
(4)	3.15				-	.75	.83	1.95**	2.60*	R_5=1.690	2.265
(5)	3.90					-	.08	1.20	1.85	R_6=1.717	2.298
(6)	3.98						-	1.12	1.77	R_7=1.738	2.325
(7)	5.10							-	.65	R_8=1.753	2.348

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 52
TASK 19 COMPARISON OF MEAN TIMES
Interior Lights - Off to Bright
Seconds

Config.		(1) B20	(2) E20	(3) A20	(4) D20	(5) A65	(6) D65	(7) E65	(8) B65	Shortest Significant Range	
	Mean	2.88	3.45	3.45	3.78	4.45	4.60	5.58	5.95	.05**	.01*
(1)	2.88	-	.57	.57	.90	1.57	1.72	2.70**	3.07**	R_2=2.110	2.860
(2)	3.45		-	.00	.33	1.00	1.15	2.13	2.50**	R_3=2.217	2.983
(3)	3.45			-	.33	1.00	1.15	2.13	2.50**	R_4=2.285	3.065
(4)	3.78				-	.67	.82	1.80	2.17	R_5=2.332	3.125
(5)	4.45					-	.15	1.13	1.50	R_6=2.369	3.171
(6)	4.60						-	.98	1.35	R_7=2.397	3.208
(7)	5.58							-	.37	R_8=2.418	3.239

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 53
TASK 20 COMPARISON OF MEAN TIMES
Exterior Lights - Off to Dim
Seconds

Config.	Mean	(1) B20	(2) A20	(3) E20	(4) A65	(5) D20	(6) D65	(7) E65	(8) B65	Shortest Significant Range .05**	.01*
		3.18	3.50	3.60	3.95	4.48	4.70	4.73	5.83		
(1)	3.18	-	.32	.42	.77	1.30	1.52	1.55	2.65*	R_2=1.486	2.014
(2)	3.50		-	.10	.45	.98	1.20	1.23	2.33*	R_3=1.561	2.100
(3)	3.60			-	.35	.88	1.10	1.13	2.23**	R_4=1.608	2.158
(4)	3.95				-	.53	.75	.78	1.88**	R_5=1.642	2.200
(5)	4.48					-	.22	.25	1.35	R_6=1.667	2.232
(6)	4.70						-	.03	1.13	R_7=1.687	2.259
(7)	4.73							-	1.10	R_8=1.703	2.280

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 54
TASK 21 COMPARISON OF MEAN TIMES
Decoy Chaff Units/Burst - 3 to C
Seconds

Config.	Mean	(1) B20	(2) A20	(3) D20	(4) E20	(5) D65	(6) A65	(7) E65	(8) B65	Shortest Significant Range .05**	.01*
		2.73	2.80	3.18	3.35	4.03	4.13	4.68	5.23		
(1)	2.73	-	.07	.45	0.62	1.30**	1.40**	1.95*	2.50*	R_2=1.048	1.420
(2)	2.80		-	.38	.55	1.23**	1.33**	1.88*	2.43*	R_3=1.101	1.481
(3)	3.18			-	.17	0.85	0.95	1.50**	2.05*	R_4=1.134	1.522
(4)	3.35				-	.68	.78	1.33**	1.88*	R_5=1.158	1.552
(5)	4.03					-	.10	0.65	1.20**	R_6=1.176	1.575
(6)	4.13						-	.55	1.10	R_7=1.190	1.593
(7)	4.68							-	.55	R_8=1.201	1.608

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 55
TASK 22 COMPARISON OF MEAN TIMES
Decoy Flares Interval - 8 to 12 Second

Config.		(1) B20	(2) D20	(3) E20	(4) A20	(5) D65	(6) A65	(7) E65	(8) B65	Shortest Significant Range	
	Mean	2.78	3.48	3.80	3.80	4.28	4.47	4.63	5.40	.05**	.01*
(1)	2.78	-	.70	1.02	1.02	1.50**	1.69**	1.85**	2.62*	R_2=1.235	1.673
(2)	3.48		-	.32	.32	0.80	0.99	1.15	1.92*	R_3=1.297	1.745
(3)	3.80			-	.00	.48	.67	.83	1.60**	R_4=1.337	1.793
(4)	3.80				-	.48	.67	.83	1.60**	R_5=1.365	1.828
(5)	4.28					-	.19	.35	1.12	R_6=1.386	1.855
(6)	4.47						-	.16	.93	R_7=1.402	1.877
(7)	4.63							-	.77	R_8=1.415	1.899

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

APPENDIX B

EYE AND HEAD MOTION DUNCAN'S MULTIPLE RANGE TESTS

Section VI provides the summary of the vertical and horizontal eye and head motion test results. This appendix provides the vertical and horizontal eye and head motion Duncan's multiple range tests.

VERTICAL EYE AND HEAD MOTION

Main effect (T) for tasks which is a comparison of mean vertical eye/head motion among the 25 tasks averaged over eight configurations and four pilots yielded a significant variance. This result, in combination with similar findings for the CxT (configurations X tasks) and PxT (pilots X tasks) interactions indicated that certain tasks in specific configuration and pilot contexts would require larger eye/head movements than others. Tasks yielding significant pairs of difference were determined by use of multiple range tests. These test results are summarized in Tables 56 to 65. The tasks were:

- o Ground Power Avionics On - Task 1
- o Auxiliary Power - Task 3
- o Landing Lights - Task 8
- o Landing Gear - Task 9
- o FBW AFCS Master - Task 10
- o Push to Jettison - Task 13
- o Anti-Ice Pitot Heat On - Task 18
- o Lights Console - Task 20
- o Decoy Panel - Task 22
- o MSD 2 - Task 24

By a simple count of significant pairs, Configuration D at 20° and 65° and Configuration E at 20° showed increased vertical eye/head movements for more tasks than other configurations.

TABLE 56
TASK 1 VERTICAL EYE AND HEAD MOTION
Ground Power Avionics On
Degrees

Config.		(1) A65	(2) A20	(3) B65	(4) D65	(5) E65	(6) E20	(7) D20	(8) B20	Shortest Significant Range	
	Mean	-45.75	-55.75	-58.00	-51.25	-64.75	-66.00	-69.00	-70.75	.05**	.01*
(1)	-45.75	-	10.00	12.25	15.50	19.00	20.25	23.25	25.00**	R_2=21.78	29.51
(2)	-55.75		-	2.25	5.50	9.00	10.25	13.25	15.00	R_3=22.87	30.78
(3)	-58.00			-	3.25	6.75	8.00	11.00	12.75	R_4=23.57	31.62
(4)	-61.25				-	3.50	4.75	7.75	9.50	R_5=24.07	32.24
(5)	-64.75					-	1.25	4.25	6.00	R_6=24.44	32.72
(6)	-66.00						-	3.00	4.75	R_7=24.73	33.10
(7)	-69.00							-	1.75	R_8=24.95	33.42

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 57
TASK 3 VERTICAL EYE AND HEAD MOTION
Auxiliary Power
Degrees

Config.		(1) E65	(2) B20	(3) B65	(4) D20	(5) D65	(6) E20	(7) A20	(8) A65	Shortest Significant Range	
	Mean	-21.50	-23.75	-25.75	-30.25	-30.50	-31.75	-43.75	-47.50	.05**	.01*
(1)	-21.50	-	2.25	4.25	8.75	9.00	10.25	22.25**	26.00*	R_2=14.79	20.06
(2)	-23.75		-	2.00	6.50	6.75	8.00	20.00**	23.75*	R_3=15.54	20.92
(3)	-25.75			-	4.50	4.75	6.00	18.00**	21.75**	R_4=16.02	21.49
(4)	-30.25				-	0.25	1.50	13.55	17.25**	R_5=16.36	21.91
(5)	-30.50					-	1.25	13.25	17.00**	R_6=16.61	22.24
(6)	-31.75						-	12.00	15.75**	R_7=16.81	22.50
(7)	-43.75							-	3.75	R_8=16.96	22.71

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 58
TASK 8 VERTICAL EYE AND HEAD MOTION
Landing Lights
Degrees

Config.		(1) A65	(2) B65	(3) B20	(4) A20	(5) D65	(6) D20	(7) E20	(8) E65	Shortest Significant Range	
	Mean	-8.25	-21.00	-22.25	-28.00	-30.50	-39.50	-40.25	-41.00	.05**	.01*
(1)	-8.25	-	12.75	14.00	19.75*	22.25*	31.25*	32.00*	32.75*	R_2=12.64	17.13
(2)	-21.00		-	1.25	7.00	9.50	18.50**	19.25*	20.00*	R_3=13.28	17.87
(3)	-22.25			-	5.75	8.25	17.25**	18.00**	18.75**	R_4=13.68	18.35
(4)	-28.00				-	2.50	11.50	12.25	13.00	R_5=13.97	18.71
(5)	-30.50					-	9.00	9.75	10.50	R_6=14.19	18.99
(6)	-39.50						-	0.75	1.50	R_7=14.35	19.21
(7)	-40.25							-	0.75	R_8=14.48	19.40

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 59
TASK 9 VERTICAL EYE AND HEAD MOTION
Landing Gear
Degrees

Config.		(1) B20	(2) A65	(3) B65	(4) A20	(5) E65	(6) D20	(7) D65	(8) E20	Shortest Significant Range	
	Mean	-9.75	-10.75	-13.75	-16.50	-36.25	-38.00	-40.00	-41.75	.05**	.01*
(1)	-9.75	-	1.00	4.00	6.75	26.50*	28.25*	30.25*	32.00*	R_2=12.03	16.30
(2)	-10.75		-	3.00	5.75	25.50*	27.25*	29.25*	31.00*	R_3=12.63	16.99
(3)	-13.75			-	2.75	22.50*	24.25*	26.25*	28.00*	R_4=13.02	17.46
(4)	-16.50				-	19.75*	21.50*	23.50*	25.25*	R_5=13.29	17.81
(5)	-36.25					-	1.75	3.75	5.50	R_6=13.50	18.07
(6)	-38.00						-	2.00	3.75	R_7=13.66	18.28
(7)	-40.00							-	1.75	R_8=13.78	18.46

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 60
TASK 10 VERTICAL EYE AND HEAD MOTION
FBW AFCS Master
Degrees

Config.		(1) A65	(2) B65	(3) A20	(4) D65	(5) B20	(6) E65	(7) E20	(8) D20	Shortest Significant Range	
	Mean	-19.00	-24.00	-30.75	-31.50	-31.75	-34.75	-38.25	-39.75	.05**	.01*
(1)	-19.00	-	5.00	11.75	12.50	12.75	15.75**	19.25*	20.75*	R_2=11.85	16.06
(2)	-24.00		-	6.75	7.50	7.75	10.75	14.25**	15.75**	R_3=12.45	16.75
(3)	-30.75			-	0.75	1.00	4.00	7.50	9.00	R_4=12.83	17.21
(4)	-31.50				-	0.25	3.25	6.75	8.25	R_5=13.10	17.55
(5)	-31.75					-	3.00	6.50	8.00	R_6=13.30	17.81
(6)	-34.75						-	3.50	5.00	R_7=13.46	18.01
(7)	-38.25							-	1.50	R_8=13.58	18.19

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 61
TASK 13 VERTICAL EYE AND HEAD MOTION
Push to Jettison
Degrees

Config.		(1) B20	(2) A65	(3) B65	(4) D20	(5) A20	(6) E20	(7) E65	(8) D65	Shortest Significant Range	
	Mean	-1.75	-2.25	-2.50	-3.50	-3.50	-3.75	-4.00	-10.50	.05**	.01*
(1)	-1.75	-	0.50	0.75	1.75	1.75	2.00	2.25	8.75**	R_2=7.56	10.25
(2)	-2.25		-	0.25	1.25	1.25	1.50	1.75	8.25	R_3=7.94	10.69
(3)	-2.50			-	1.00	1.00	1.25	1.50	8.00	R_4=8.18	10.98
(4)	-3.50				-	0.00	0.25	0.50	7.00	R_5=8.36	11.19
(5)	-3.50					-	0.25	0.50	7.00	R_6=8.48	11.36
(6)	-3.75						-	0.25	6.75	R_7=8.59	11.49
(7)	-4.00							-	6.50	R_8=8.66	11.60

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 62
TASK 18 VERTICAL EYE AND HEAD MOTION
Anti-Ice Pitot Heat On
Degrees

Config.		(1) B65	(2) B20	(3) A20	(4) A65	(5) E65	(6) D65	(7) D20	(8) E20	Shortest Significant Range	
	Mean	-18.00	-25.25	-25.75	-26.25	-48.00	-49.00	-63.75	-66.50	.05**	.01*
(1)	-18.00	-	7.25	7.75	8.25	30.00**	31.00**	45.75*	48.50*	R_2=21.34	28.92
(2)	-25.25		-	0.50	1.00	22.75	23.75**	38.50*	41.25*	R_3=22.41	30.16
(3)	-25.75			-	0.50	22.25	23.25**	38.00*	40.75*	R_4=23.10	30.99
(4)	-26.25				-	21.75	22.75**	37.50	40.25*	R_5=23.58	31.59
(5)	-48.00					-	1.00	15.75	18.50	R_6=23.95	32.06
(6)	-49.00						-	14.75	17.50	R_7=24.23	32.43
(7)	-63.75							-	2.75	R_8=24.45	32.75

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 63
TASK 20 VERTICAL EYE AND HEAD MOTION
Interior Lights Console - Off to Bright
Degrees

Config.		(1) A65	(2) B20	(3) B65	(4) E65	(5) D65	(6) A20	(7) E20	(8) D20	Shortest Significant Range	
	Mean	-32.50	-35.50	-37.25	-41.50	-42.00	-48.50	-55.00	-59.50	.05**	.01*
(1)	-32.50	-	3.00	4.75	9.00	9.50	16.00	22.50	27.00**	R_2=22.39	30.34
(2)	-35.50		-	1.75	6.00	6.50	13.00	19.50	24.00	R_3=23.52	31.65
(3)	-37.25			-	4.25	4.75	11.25	17.75	22.25	R_4=24.23	32.51
(4)	-41.50				-	0.50	7.00	13.50	18.00	R_5=24.74	33.15
(5)	-42.00					-	6.50	13.00	17.50	R_6=25.89	33.64
(6)	-48.50						-	6.50	11.00	R_7=25.43	34.03
(7)	-55.00							-	4.50	R_8=25.66	34.36

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 64
TASK 22 VERTICAL EYE AND HEAD MOTION
Decoy Panel Chaff Units Burst 3 to C
Degrees

Config.		(1) B65	(2) B20	(3) D65	(4) A65	(5) E65	(6) A20	(7) E20	(8) D20	Shortest Significant Range	
	Mean	-19.75	-30.75	-35.25	-36.75	-37.50	-42.75	-52.75	-56.25	.05**	.01*
(1)	-19.75	-	11.00	15.50	17.00	17.75	23.00	33.00**	36.50*	R_2=23.85	32.32
(2)	-30.75		-	4.50	6.00	6.75	12.00	22.00	25.50	R_3=25.05	33.71
(3)	-35.25			-	1.50	2.25	7.51	17.50	21.00	R_4=25.82	34.63
(4)	-36.75				-	0.75	6.00	16.00	19.50	R_5=26.36	35.31
(5)	-37.50					-	5.25	15.25	18.75	R_6=26.76	35.83
(6)	-42.75						-	10.00	13.50	R_7=27.08	36.25
(7)	-52.75							-	3.50	R_8=27.33	36.60

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 65
TASK 24 VERTICAL EYE AND HEAD MOTION
MSD 2
Degrees

Config.		(1) E65	(2) D65	(3) B20	(4) A65	(5) B65	(6) A20	(7) D20	(8) E20	Shortest Significant Range	
	Mean	-1.75	-10.25	-11.25	-11.50	-13.25	-13.75	-17.25	-18.25	.05**	.01*
(1)	-1.75	-	8.50	0.50	9.75	11.50	12.00	15.50**	16.50*	R_2=11.44	15.51
(2)	-10.25		-	1.00	1.25	3.00	3.50	7.00	8.00	R_3=11.99	16.17
(3)	-11.25			-	0.25	2.00	2.50	6.00	7.00	R_4=12.39	16.62
(4)	-11.50				-	1.75	2.25	5.75	6.75	R_5=12.65	16.94
(5)	-13.25					-	0.50	4.00	5.00	R_6=12.84	17.19
(6)	-13.75						-	3.50	4.50	R_7=12.99	17.39
(7)	-17.25							-	1.00	R_8=13.11	17.56

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

HORIZONTAL EYE AND HEAD MOTION

Main effect (T) for tasks which is a comparison of mean horizontal eye/head motion among the 25 tasks averaged over eight configurations and four pilots yielded a significant variance. This result, in combination with similar findings for the CxT (configurations X tasks) and PxT (pilots X tasks) interactions, indicated that certain tasks in specific configuration and pilot contexts would require larger eye/head movements than others. Tasks yielding significant pairs of difference were determined by use of multiple range tests. These test results are summarized in Tables 66 to 85. All tasks which exhibited significant variations on the vertical eye/head plane also showed significant differences in the horizontal eye/head plane. Increased total horizontal motion was revealed for the following additional tasks:

- Emergency Speed Bre - Task 2
- BIT TCN - Task 4
- UHF Communications Channel - Task 5
- Select Jettison - Combat to Stores - Task 7
- Jammer Pushbutton - Task 12
- Master Arm - Task 14
- VI Master Mode - Task 15
- Temperature Panel Air Source Off to Both - Task 19
- Decoy Panel Flares Internal - Task 23
- MSD 4 - Task 25

By a simple count of significant pairs, Configurations D and E at 20° showed increased horizontal eye/head movements for more tasks than other configurations.

TABLE 66
TASK 1 HORIZONTAL EYE AND HEAD MOTION
Ground Power Avionics On
Degrees

Config.	(1) A65	(2) D65	(3) A20	(4) B20	(5) E65	(6) B65	(7) E20	(8) D20	Shortest Significant Range	
Mean	-58.50	-61.50	-62.75	-65.75	-69.25	-69.25	-83.00	-83.00	.05**	.01*
(1) -58.50	-	3.00	4.25	7.25	20.50	35.07*	34.50*	34.50*	R_2=22.33	30.22
(2) -61.50		-	1.25	4.25	20.50	35.07*	34.50*	34.50*	R_3=23.45	31.56
(3) -62.75			-	3.00	7.50	7.75	21.50	21.50	R_4=24.17	32.43
(4) -65.75				-	6.50	6.50	20.25	20.25	R_5=24.68	33.06
(5) -69.00					-	0.25	14.00	14.00	R_6=25.06	33.55
(6) -69.25						-	13.75	13.75	R_7=25.36	33.94
(7) -83.00							-	-	R_8=25.59	34.27

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*SIGNIFICANT(P<.01)
**SIGNIFICANT(P<.05)

TABLE 67
TASK 2 HORIZONTAL EYE AND HEAD MOTION
Emergency Speed Brake
Degrees

Config.	(1) A65	(2) D65	(3) A20	(4) E65	(5) B65	(6) B20	(7) E20	(8) D20	Shortest Significant Range	
Mean	-42.75	-50.25	-53.25	-53.25	-53.50	-57.75	-61.25	-65.00	.05**	.01*
(1) -42.75	-	7.50	10.50	10.50	10.75	15.00	18.50**	22.25**	R_2=14.83	20.10
(2) -50.25		-	3.00	3.00	3.25	7.75	11.00	14.75	R_3=15.57	20.96
(3) -53.25			-	0.00	0.25	4.50	8.00	11.75	R_4=16.05	21.53
(4) -53.25				-	0.25	4.50	8.00	11.75	R_5=16.39	21.96
(5) -53.50					-	4.50	7.75	11.50	R_6=16.64	22.28
(6) -57.75						-	3.50	7.25	R_7=16.84	22.54
(7) -61.25							-	3.75	R_8=16.99	22.76

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 68
TASK 3 HORIZONTAL EYE AND HEAD MOTION
Auxiliary Power
Degrees

Config.		(1) E65	(2) B65	(3) D65	(4) B20	(5) A65	(6) D20	(7) A20	(8) E20	Shortest Significant Range	
	Mean	-30.75	-37.00	-41.75	-43.25	-45.00	-45.50	-45.57	-46.50	.05**	.01*
(1)	-30.75	-	6.25	11.00	12.50	14.25	14.75	14.82	15.75**	R_2=13.43	18.20
(2)	-37.00		-	4.75	6.25	8.00	8.50	8.57	9.50	R_3=14.10	18.98
(3)	-41.75			-	1.50	3.25	3.75	3.82	4.75	R_4=14.54	19.50
(4)	-43.25				-	1.75	2.25	2.32	3.25	R_5=14.84	19.88
(5)	-45.00					-	0.50	0.57	1.50	R_6=15.07	20.18
(6)	-45.50						-	0.07	1.00	R_7=15.25	20.41
(7)	-45.57							-	0.93	R_8=15.39	20.61

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 69
TASK 4 HORIZONTAL EYE AND HEAD MOTION
BIT TACAN Push Button
Degrees

Config.		(1) A65	(2) A20	(3) D65	(4) B65	(5) E65	(6) B20	(7) F20	(8) D20	Shortest Significant Range	
	Mean	-50.75	-54.00	-59.25	-60.25	-63.75	-67.25	-67.25	-79.75	.05**	.01*
(1)	-50.75	-	3.25	8.50	9.50	13.00	16.50	16.50	29.00*	R_2=14.65	19.86
(2)	-54.00		-	5.25	6.25	9.75	13.25	13.25	25.75*	R_3=15.39	20.71
(3)	-59.25			-	1.00	4.50	8.00	8.00	20.50**	R_4=15.86	21.28
(4)	-60.25				-	3.50	7.00	7.00	19.50**	R_5=16.19	21.70
(5)	-63.75					-	3.50	3.50	16.00**	R_6=16.45	22.02
(6)	-67.25						-	0.00	12.50	R_7=16.64	22.27
(7)	-76.25							-	3.50	R_8=16.79	22.49

(1) (2) (3) (4) (5) (6) (7) (8)

*Significant (P<.01)
**Significant (P<.05)

Means not underscored by the same line are significantly different.

TABLE 70
TASK 5 HORIZONTAL EYE AND HEAD MOTION
UHF Communication Channel
Degrees

Config.		(1) A65	(2) A20	(3) B65	(4) E65	(5) D65	(6) B20	(7) E20	(8) D20	Shortest Significant Range	
	Mean	-42.75	-46.00	-49.25	-51.00	-51.50	-55.00	-56.25	-59.25	.05**	.01*
(1)	-42.75	-	3.25	6.50	8.25	8.75	12.25	13.50	16.50**	R_2=13.34	18.08
(2)	-46.00		-	3.25	5.00	5.50	9.00	10.25	13.25	R_3=14.01	18.86
(3)	-49.25			-	1.75	2.25	5.75	7.00	10.00	R_4=14.44	19.37
(4)	-51.00				-	0.50	4.00	5.25	8.25	R_5=14.74	19.75
(5)	-51.50					-	3.50	4.75	7.75	R_6=14.97	20.04
(6)	-55.00						-	1.25	4.25	R_7=15.15	20.28
(7)	-56.25							-	3.00	R_8=15.29	20.47

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 71
TASK 7 HORIZONTAL EYE AND HEAD MOTION
Select Jettison Combat to Stores
Degrees

Config.		(1) A65	(2) A20	(3) B65	(4) E65	(5) D65	(6) D20	(7) B20	(8) E20	Shortest significant Range	
	Mean	-36.75	-39.75	-40.75	-44.75	-48.50	-49.50	-51.00	-56.00	.05**	.01*
(1)	-36.75	-	3.00	4.00	8.00	11.75	12.75	14.25**	19.25*	R_2=11.98	16.22
(2)	-39.75		-	1.00	5.00	8.75	9.75	11.25	16.25*	R_3=12.57	16.92
(3)	-40.75			-	3.75	7.75	8.75	10.25	15.25**	R_4=12.96	17.38
(4)	-44.75				-	3.75	4.75	6.25	11.25	R_5=13.23	17.72
(5)	-48.50					-	1.00	2.50	7.50	R_6=13.43	17.98
(6)	-49.50						-	1.00	6.50	R_7=13.59	18.19
(7)	-51.00							-	5.00	R_8=13.72	18.37

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 72
TASK 8 HORIZONTAL EYE AND HEAD MOTION
Landing Lights
Degrees

Config.		(1) B65	(2) A65	(3) B20	(4) A20	(5) E20	(6) D20	(7) E65	(8) D65	Shortest Significant Range	
	Mean	-25.25	-26.75	-29.50	-30.25	-40.00	-40.50	-43.75	-44.25	.05**	.01*
(1)	-25.25	-	1.50	4.25	5.00	14.75**	15.25**	18.50*	19.00*	R_2=10.13	13.73
(2)	-26.75		-	2.75	3.50	13.25**	13.75**	17.00*	17.50*	R_3=10.64	14.32
(3)	-29.50			-	0.75	10.50	11.00	14.25**	14.75**	R_4=10.97	14.71
(4)	-30.25				-	9.75	10.25	13.50**	14.00**	R_5=11.19	15.00
(5)	-40.00					-	.50	5.50	4.25	R_6=11.37	15.22
(6)	-40.50						-	3.25	3.75	R_7=11.50	15.40
(7)	-43.75							-	.50	R_8=11.61	15.55

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 73
TASK 9 HORIZONTAL EYE AND HEAD MOTION
Landing Gear
Degrees

Config.		(1) A65	(2) B65	(3) A20	(4) B20	(5) E65	(6) D20	(7) D65	(8) E20	Shortest Significant Range	
	Mean	-27.00	-31.00	-31.25	-37.00	-44.50	-48.25	-48.50	-49.75	.05**	.01*
(1)	-27.00	-	4.00	4.25	10.00**	17.50*	21.25*	21.50*	22.75*	R_2= 9.14	12.38
(2)	-31.00		-	0.25	6.00	13.50*	17.25*	17.50*	18.75*	R_3= 9.59	12.91
(3)	-31.25			-	5.75	13.25*	17.00*	17.25*	18.50*	R_4= 9.89	13.27
(4)	-37.00				-	7.50	11.25**	11.50**	12.75**	R_5=10.10	13.53
(5)	-44.50					-	3.75	4.00	5.25	R_6=10.25	13.73
(6)	-48.75						-	0.25	1.50	R_7=10.38	13.89
(7)	-48.50							-	1.25	R_8=10.47	14.02

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 74
TASK 10 HORIZONTAL EYE AND HEAD MOTION
FBW AFCS Master
Degrees

Config.		(1) A65	(2) E65	(3) A20	(4) B20	(5) B65	(6) D20	(7) D65	(8) E20	Shortest Significant Range	
	Mean	-22.75	-24.25	-25.50	-27.25	33.75	42.00	42.00	45.25	.05**	.01*
(1)	-22.75	-	1.50	2.75	4.50	11.00	19.25**	19.25**	22.50**	R_2=15.70	21.28
(2)	-24.25		-	1.25	3.00	9.50	17.75**	17.75**	21.00**	R_3=16.50	22.20
(3)	-25.50			-	1.75	8.25	16.50	16.50	19.75**	R_4=17.00	22.81
(4)	-27.25				-	6.50	14.75	14.75	18.00**	R_5=17.36	23.29
(5)	-33.75					-	23.00	23.00	11.50	R_6=17.62	23.60
(6)	-42.00						-	0.00	3.25	R_7=17.83	23.87
(7)	-42.00							-	3.25	R_8=17.99	24.10

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 75
TASK 12 HORIZONTAL EYE AND HEAD MOTION
Jammer Push Button
Degrees

Config.		(1) D65	(2) B65	(3) A65	(4) A20	(5) E65	(6) B20	(7) E20	(8) D20	Shortest Significant Range	
	Mean	-18.25	-18.50	-20.25	-21.25	-24.50	-24.75	-25.50	-28.00	.05**	.01*
(1)	-18.25	-	0.25	2.00	3.00	6.25	6.50	7.25	9.75**	R_2= 6.42	8.70
(2)	-18.50		-	1.75	2.75	6.00	6.25	7.00	9.50**	R_3= 6.75	9.08
(3)	-20.25			-	1.00	4.25	4.50	5.25	7.75**	R_4= 6.95	9.33
(4)	-21.25				-	3.25	3.50	4.25	6.75	R_5= 7.10	9.51
(5)	-24.50					-	0.25	1.50	3.50	R_6= 7.21	9.65
(6)	-24.75						-	0.75	3.25	R_7= 7.29	9.76
(7)	-25.50							-	-	R_8= 7.36	9.86

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 76
TASK 13 HORIZONTAL EYE AND HEAD MOTION
Push to Jettison
Degrees

Config.		(1) B65	(2) E65	(3) B20	(4) E20	(5) D20	(6) A20	(7) D65	(8) A65	Shortest Significant Range	
	Mean	-7.25	-9.00	-9.25	-9.25	-10.25	-10.50	-12.75	-13.25	.05**	.01*
(1)	- 7.25	-	1.75	2.00	2.00	3.00	3.25	5.50**	6.00**	R_2= 4.20	5.70
(2)	- 9.00		-	0.25	0.25	1.25	1.50	3.75	4.25	R_3= 4.42	5.94
(3)	- 9.25			-	0.00	1.00	1.25	3.50	4.00	R_4= 4.55	6.10
(4)	- 9.25				-	1.00	1.25	3.50	4.00	R_5= 4.65	6.22
(5)	-10.25					-	0.25	2.50	3.00	R_6= 4.72	6.32
(6)	-10.50						-	2.25	2.75	R_7= 4.77	6.39
(7)	-12.75							-	0.50	R_8= 4.82	6.45

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 77
TASK 14 HORIZONTAL EYE AND HEAD MOTION
Master Arm
Degrees

Config.		(1) A65	(2) B65	(3) A20	(4) E65	(5) D65	(6) B20	(7) D20	(8) E20	Shortest Significant Range	
	Mean	-13.50	-14.00	-15.25	-16.50	-17.00	-20.50	-22.50	-23.50	.05**	.01*
(1)	-13.50	-	0.50	1.75	3.00	3.50	7.00	9.00**	10.00**	R_2= 6.60	8.94
(2)	-14.00		-	1.25	2.50	3.00	6.50	8.50**	9.50**	R_3= 6.93	9.32
(3)	-15.25			-	1.25	1.75	5.25	7.25	8.25**	R_4= 7.14	9.58
(4)	-16.50				-	0.50	4.00	6.00	7.00	R_5= 7.29	9.77
(5)	-17.00					-	3.50	5.50	6.50	R_6= 7.40	9.91
(6)	-20.50						-	2.00	3.00	R_7= 7.49	10.03
(7)	-22.50							-	1.50	R_8= 7.56	10.12

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 78
TASK 15 HORIZONTAL EYE AND HEAD MOTION
VI Master Mode
Degrees

Config.	Mean	(1) B65 -10.25	(2) A65 -10.50	(3) A20 -11.50	(4) D65 -11.50	(5) E65 -11.50	(6) B20 -13.75	(7) E20 -15.25	(8) D20 -15.75	Shortest Significant Range .05**	.01*
(1)	-10.25	-	0.25	1.25	1.25	1.25	3.50	5.00	5.50**	R_2=4.35	5.89
(2)	-10.50		-	1.00	1.00	1.00	3.25	4.75	5.25**	R_3=4.57	6.15
(3)	-11.50			-	0.00	0.00	2.25	3.75	4.25**	R_4=4.71	6.32
(4)	-11.50				-	0.00	2.25	3.75	4.25**	R_5=4.81	6.44
(5)	-11.50					-	2.25	3.75	4.25**	R_6=4.88	6.54
(6)	-13.75						-	1.50	2.00	R_7=4.94	6.61
(7)	-15.25							-		R_8=4.98	6.68

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 79
TASK 18 HORIZONTAL EYE AND HEAD MOTION
Anti-Ice Pitot Heat On
Degrees

Config.	Mean	(1) A20 22.00	(2) A65 25.25	(3) B65 30.75	(4) B20 31.25	(5) D65 46.25	(6) E65 50.00	(7) E20 63.00	(8) D20 64.25	Shortest Significant Range .05**	.01*
(1)	22.00	-	3.25	8.75	9.25	24.25*	28.00*	41.00*	42.25*	R_2= 9.28	12.58
(2)	25.25		-	5.50	6.00	21.00*	24.75*	37.75*	39.00*	R_3= 9.75	13.12
(3)	30.75			-	0.50	15.50*	19.25*	32.25*	33.50*	R_4=10.05	13.48
(4)	31.25				-	15.00*	18.75*	31.75*	33.00*	R_5=10.26	13.74
(5)	46.25					-	3.75	16.75**	18.00*	R_6=10.42	13.95
(6)	50.00						-	13.00**	14.25*	R_7=10.54	14.11
(7)	63.00							-	1.25	R_8=10.64	14.25

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 80
TASK 19 HORIZONTAL EYE AND HEAD MOTION
Temperature Panel Air Source Off to Both
Degrees

Config.		(1) B20	(2) A65	(3) B65	(4) D65	(5) A20	(6) E65	(7) D20	(8) E20	Shortest Significant Range	
	Mean	36.00	36.00	39.75	39.75	40.75	40.75	47.25	52.50	.05**	.01*
(1)	36.00	-	0.00	3.75	3.75	4.75	4.75	11.25	16.50*	R_2=10.63	14.40
(2)	36.00		-	3.75	3.75	4.75	4.75	11.25	16.50*	R_3=11.16	15.02
(3)	39.75			-	0.00	1.00	1.00	7.50	12.75*	R_4=11.50	15.43
(4)	39.75				-	1.00	1.00	7.50	12.75*	R_5=11.74	15.73
(5)	40.75					-	0.00	6.50	11.75**	R_6=12.29	15.97
(6)	40.75						-	6.50	11.75**	R_7=12.07	16.15
(7)	47.25							-	5.25	R_8=12.17	16.31

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant ($P<.01$)
**Significant ($P<.05$)

TABLE 81
TASK 20 HORIZONTAL EYE AND HEAD MOTION
Interior Lights Console Off to Bright
Degrees

Config.		(1) A65	(2) D65	(3) B65	(4) E65	(5) B20	(6) A20	(7) E20	(8) D20	Shortest Significant Range	
	Mean	36.00	40.25	41.25	41.75	42.50	47.75	55.75	56.25	.05**	.01*
(1)	36.00	-	4.25	5.25	5.75	6.50	11.75	19.75*	20.25*	R_2=12.20	16.54
(2)	40.25		-	1.00	1.50	2.25	7.50	15.50**	16.00**	R_3=12.82	17.24
(3)	41.25			-	0.50	1.25	6.50	14.50**	15.00**	R_4=13.21	17.72
(4)	41.75				-	0.75	6.00	14.00**	14.50**	R_5=13.48	18.07
(5)	42.50					-	5.25	13.25**	13.75**	R_6=13.69	18.33
(6)	47.75						-	8.00	8.50	R_7=13.86	18.55
(7)	55.75							-	0.50	R_8=13.98	18.73

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant ($P<.01$)
**Significant ($P<.05$)

TABLE 82
TASK 22 HORIZONTAL EYE AND HEAD MOTION
Decoy Panel Chaff Units Burst 3 to C
Degrees

Config.		(1) B20	(2) A65	(3) E65	(4) B65	(5) A20	(6) D65	(7) D20	(8) E20	Shortest Significant Range	
	Mean	46.25	53.50	57.50	57.75	59.00	59.75	70.75	73.50	.05**	.01*
(1)	46.25	-	7.25	11.25	11.50	12.75	13.50	24.50**	27.25**	R_2=18.83	25.52
(2)	53.50		-	4.00	4.25	5.50	13.25	17.25	20.00	R_3=19.78	26.61
(3)	57.50			-	0.25	1.50	2.25	13.25	16.00	R_4=20.38	27.34
(4)	57.75				-	1.25	2.00	13.00	15.75	R_5=20.81	27.88
(5)	59.00					-	0.75	11.75	14.50	R_6=21.13	28.29
(6)	59.75						-	11.00	13.75	R_7=21.38	28.62
(7)	70.75							-	2.75	R_8=21.58	28.89

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 83
TASK 23 HORIZONTAL EYE AND HEAD MOTION
Decoy Panel Flares Internal 2 to 12
Degrees

Config.		(1) D65	(2) A65	(3) B20	(4) B65	(5) A20	(6) E65	(7) E20	(8) D20	Shortest Significant Range	
	Mean	60.25	60.75	62.00	62.00	66.25	68.00	76.76	80.75	.05**	.01*
(1)	60.25	-	0.50	1.75	1.75	6.00	7.75	16.51	20.50**	R_2=17.66	23.93
(2)	60.75		-	1.25	1.25	[illegible]	7.25	16.01	20.00**	R_3=18.55	24.96
(3)	62.00			-	0.00	4.25	6.00	14.76	18.75	R_4=19.12	25.65
(4)	62.00				-	4.25	6.00	14.76	18.75	R_5=19.52	26.15
(5)	66.25					-	1.75	10.51	14.50	R_6=19.82	26.54
(6)	68.00						-	8.76	12.75	R_7=20.06	26.84
(7)	76.76							-	3.99	R_8=20.24	27.10

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 84
TASK 24 HORIZONTAL EYE AND HEAD MOTION
MSD 2
Degrees

Config.		(1) A20	(2) E65	(3) D20	(4) D65	(5) B20	(6) A65	(7) B65	(8) E65	Shortest Significant Range	
	Mean	-0.00	-0.75	-0.75	1.50	1.75	2.50	3.00	4.50	.05**	.01*
(1)	-0.00	-	0.75	0.75	1.50	1.75	2.50	3.00	4.50**	R_2= 3.91	5.30
(2)	-0.75		-	0.00	0.50	1.00	1.75	2.25	3.75	R_3= 4.11	5.53
(3)	-0.75			-	0.75	1.00	1.75	2.25	3.75	R_4= 4.23	5.68
(4)	1.50				-	0.25	1.00	1.50	3.00	R_5= 4.32	5.79
(5)	1.75					-	0.75	1.25	2.75	R_6= 4.39	5.88
(6)	2.50						-	0.50	2.00	R_7= 4.44	5.95
(7)	3.00							-	1.50	R_8= 4.48	6.00

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

TABLE 85
TASK 25 HORIZONTAL EYE AND HEAD MOTION
MSD 4
Degrees

Config.		(1) A65	(2) D65	(3) A20	(4) E65	(5) B65	(6) D20	(7) E20	(8) B20	Shortest Significant Range	
	Mean	7.25	8.00	8.75	9.25	10.00	10.50	11.75	15.25	.05**	.01*
(1)	7.25	-	0.75	1.50	2.00	2.75	3.25	4.50	8.00**	R_2=5.75	7.79
(2)	8.00		-	0.75	1.25	2.00	2.50	3.75	7.25**	R_3=6.04	8.13
(3)	8.75			-	0.50	1.25	1.75	3.00	6.50**	R_4=6.23	8.35
(4)	9.25				-	0.75	1.25	2.50	6.00	R_5=6.36	8.51
(5)	10.00					-	0.50	1.75	5.25	R_6=6.45	8.64
(6)	10.50						-	1.25	4.75	R_7=6.53	8.74
(7)	11.75							-	3.50	R_8=6.59	8.83

(1) (2) (3) (4) (5) (6) (7) (8)

Means not underscored by the same line are significantly different.

*Significant (P<.01)
**Significant (P<.05)

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APPENDIX C

PAIRED COMPARISONS RESULTS

Questionnaires were prepared for the following areas: mission phases, control/displays, cockpit configuration and control/display location. These questionnaires consisted of sets of paired comparisons which were used to derive preference ranking scales. The subjects' task was greatly simplified because he was only required to rank the two items being considered for any given comparison. Summary results are provided in Section VI. Detailed results related to the control/displays and control/display locations are illustrated in this appendix.

CONTROL/DISPLAY COMPARISONS

The pilots judged which control/display group had greater importance in terms of impact on the crew station during the mission and each mission phase. Specific equipment related to these groups are identified in Table 86. Figures 48 to 58 show the ranks of the combined scores for each mission phase.

TABLE 86
CONTROL/DISPLAY PAIRED COMPARISON CATEGORIES

Paired Comparison Category	Control/Display Equipment	
	No.	Title
(A) Communications and Identification	7	Comm/AAI Controls (Avionics Panel - AP)
	8	Identification Friend or Foe (IFF) Controls (AP)
	26	Comm Control (THR)
	27	IFF Interrogate Control (THR)
	37	Comm I/P Light
	73	Channel/Freq/Mode Display
	100	Comm/Oxygen Connectors
	102	Clock/Magnetic Compass
(B) Flight Instruments	45	Head Up Display (HUD) (ADI) Mode
	46	Angle of Attack Indicator
	47	Accelerometer
	48	Vertical Velocity Indicator
	49	Multisensor Display 1 (MSD 1) (ADI Mode)
	51	Airspeed/Mach Indicator
	52	Altimeter
	53	Multisensor Display 2 (MSD 2) (ADI Mode)
	58	Standby Airspeed Indicator
	59	Standby Attitude Direction Indicator
	60	Standby Altimeter
	75	Wing Tip Position Indicator
	79	Rain Repel Control

TABLE 86 (Continued)
CONTROL/DISPLAY PAIRED COMPARISON CATEGORIES

Paired Comparison Category	Control/Display Equipment	
	No.	Title
(C) Flight Control and Propulsion	2	Ground Power Control Panel
	3	Emergency Speed Brake Control
	5	Emergency Brake/Steering Handle
	6	Engine Air Start Control
	17	Throttle - Left (Outbd) and Right (Inbd)
	19	Servo Drive Mode Select (THR)
	21	Left Engine Cutoff Finger Lift (THR)
	22	Servo Drive Control (THR)
	24	Speed Brake/Mod Drag Mode Select (THR)
	25	Speed Brake/Mod Drag Control (THR)
	45	Head Up Display
	80	Oxygen Control Panel
	81	Anti-Ice Control Panel
	82	Rudder Pedal Adjust Control
	83	Flight Controller (Flt Cont)
	85	Trim (Flt Cont)
	86	Direct Lift/Direct Side Force Control (Flt Cont)
	87	Takeoff Trim Control (Flt Cont)
	92	Nose Gear Steer (Flt Cont)
	93	Generator Control Panel
	95	Temp Control Panel
	100	Comm/Oxygen Control
	108	Rudder Pedals (L/R)
(D) Sensor Units	9	Sensor Controls (AP)
	10	Head Up Display/Camera (HUD/CMR) Controls (AP)
	11	Displays Controls (AP)
	18	Radar Elev Position Control (THR)
	19	Radar Designate Mode Select (THR)
	22	Radar Target Designator (THR)
	45	Head Up Displays
	49	MSD 1 (EO and Rdr) - Tgt Detection and Recognition
	50	MSD 1 Mode Select Controls
	53	MSD 2
	54	MSD 3
	113	MSD 4
(E) Navigation	12	Navigation Controls
	13	Navigation Aids Control
	45	Head Up Display
	53	MSD 2 (Moving Map Display)
	54	MSD 3 (Moving Map Display)
	55	Marker Beacon Indicator Light
	56	Navigation Display Panel
	57	Inertial Navigation System Controls (Fixed Control Only)
	64	Master Mode Select Controls
	101	Storage Area
	102	Clock/Magnetic Compass

TABLE 86 (Continued)
CONTROL/DISPLAY PAIRED COMPARISON CATEGORIES

Paired Comparison Category	Control/Display Equipment	
	No.	Title
(F) Threat Warning (TEWS)	14 28 49 50 53 54 63 99 113	TEWS Controls (AP) ECM Dispenser Controls (THR) MSD 1 TEWS MSD 1 Mode Select Controls MSD 2 (TEWS) MSD 3 (TEWS) AI/SAM TEWS Warning Light Decoy Dispenser Programmer MSD 4 (TEWS)
(G) Engine Instruments	15 67 68 69 70 71 74 77	Fuel Control Panel Oil Pressure Indicators (L/R Engines) Fuel Flow Indicator Turbine Inlet Temp Indicator RPM Indicator Nozzle Position Indicator Fuel Quantity Indicator/Bingo Light Hydraulic Pressure Indicators (PC1, PC2, UTL)
(H) Caution and Warning	39 41 43 44 61 62 65 66 72 76 78 94	Left Engine Fire Warning Light/Control Emergency Jettison Control Master Caution Indicator Caution Light Panel Cricuit Breaker Panels Air Vent May Day Call Pushbutton Right Engine Fire Warning Light/Control Canopy Unlocked Warning Light Cabin Pressure Indicator Liquid Oxygen Qty Indicator Emergency Vent Control
(I) Lighting and Misc	16 62 96 97 98	Landing/Taxi Light Control Air Vent Interior Lighting Control Panel Exterior Lighting Control Panel Utility Flood Light
(J) Built-in-Test	4	Built-in-Test Control Panel
(K) Weapons Delivery	20 23 34 35 36 38 40 42 45 49	Missile Uncage Control (THR) Weapon Mode Select Control (THR) Armament Control Panel Easy Access Mode Controls Reticle Depression Control Standby Reticle On Light Gunfire Rate Control - High/Low Master Arm Control HUD MSD 1 (EO and Rdr) - Target Lock-on

TABLE 88 (Continued)
CONTROL/DISPLAY PAIRED COMPARISON CATEGORIES

Paired Comparison Category	Control/Display Equipment	
	No.	Title
(K) Weapons Delivery	50	MSD 2 (EO and Rdr) - Target Lock-on
	64	Master Mode Select Controls
	84	Weapon Release Control (Flt Cont)
	85	Manual Fus Aim Control (Flt Cont)
	86	Direct Lift/Direct Side Force Control
	92	Auto Fus Aim Control (Flt Cont)
	113	MSD 4 (EO and Rdr) - Target Lock-on
(L) Ejection Seat/ High G Seat	88	Vertical Seat Adjust Control
	90	Seat Position Up Control
	91	Seat Position Down Control
	103	Shoulder Harness Release
	104	Canopy Control
	105	Ejection Control
	106	Manual Seat Positioning Control

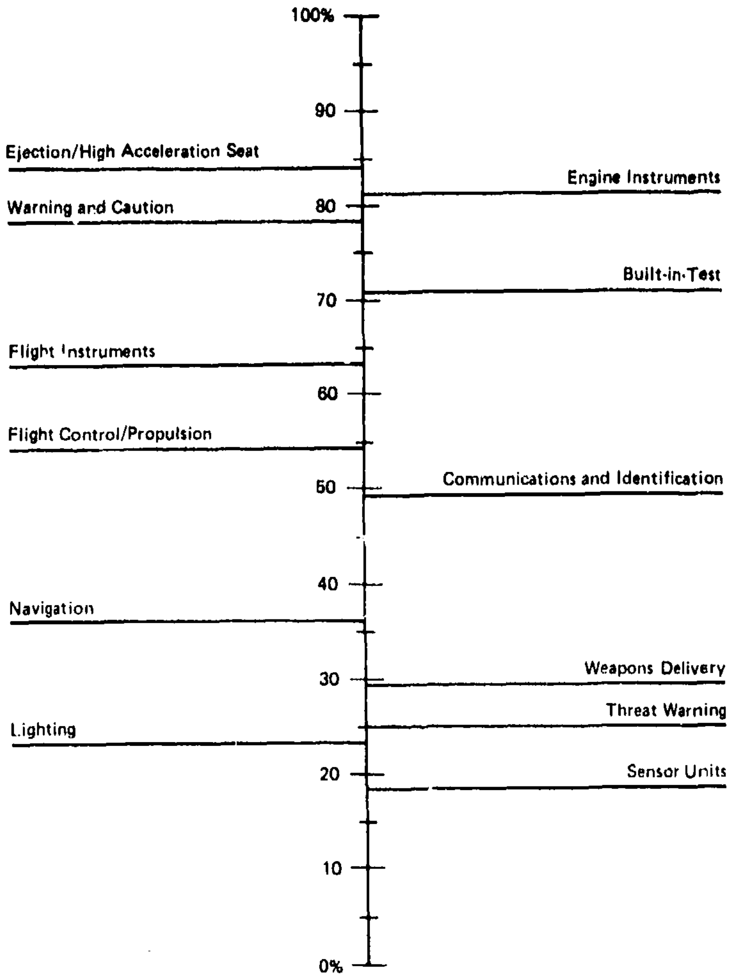

FIGURE 48
CONTROL/DISPLAY IMPORTANCE FOR PREFLIGHT

GP74-0757 38

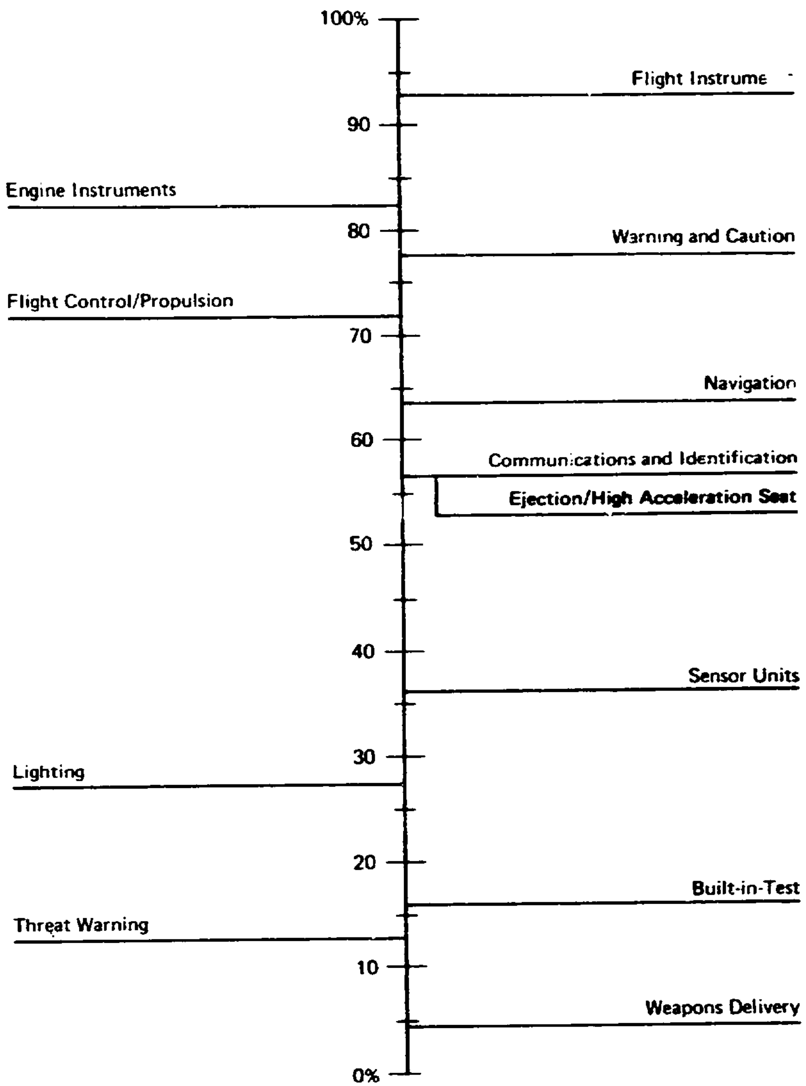

FIGURE 49
CONTROL/DISPLAY IMPORTANCE FOR TAKEOFF AND CLIMB

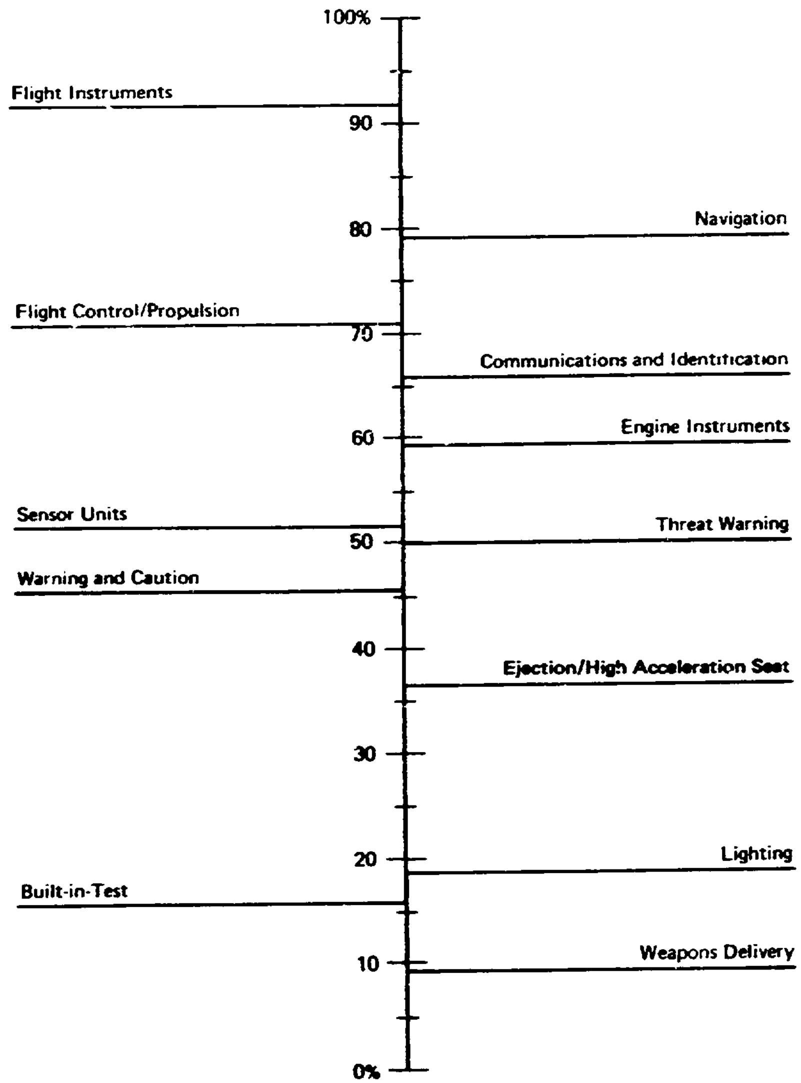

FIGURE 50
CONTROL/DISPLAY IMPORTANCE FOR CRUISE

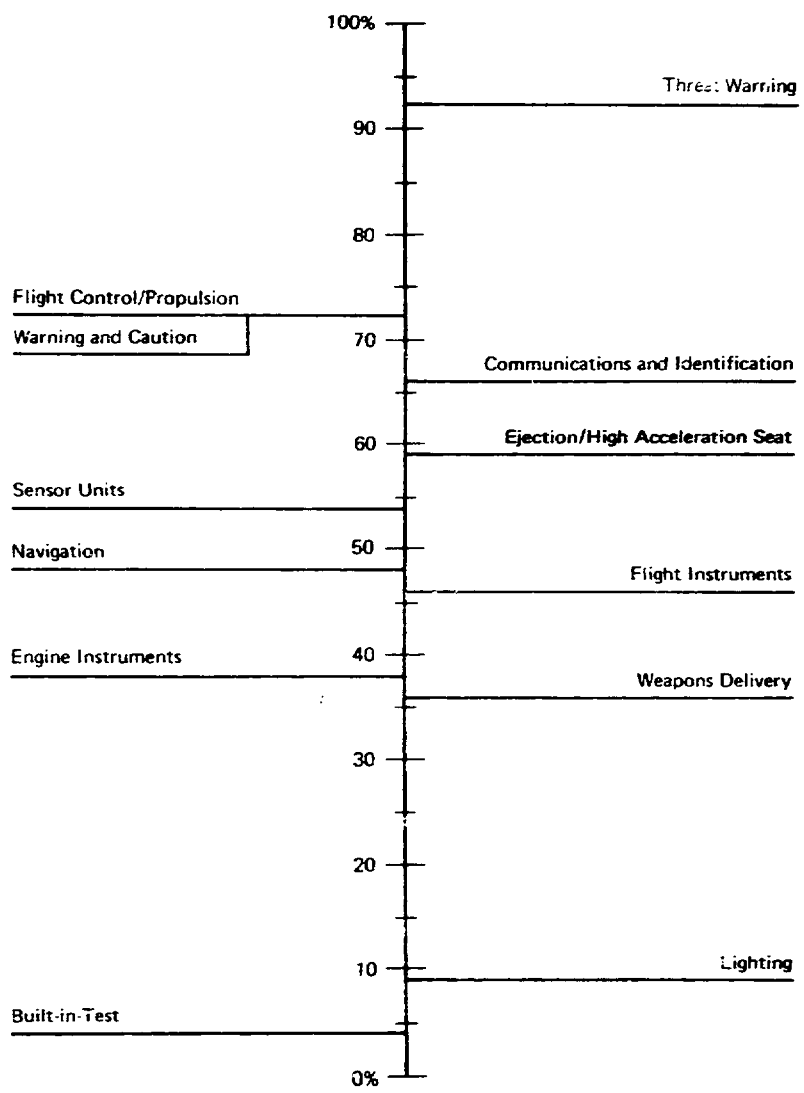

FIGURE 51
CONTROL/DISPLAY IMPORTANCE FOR SAM PENETRATION/EVASION

GP74-0757-41

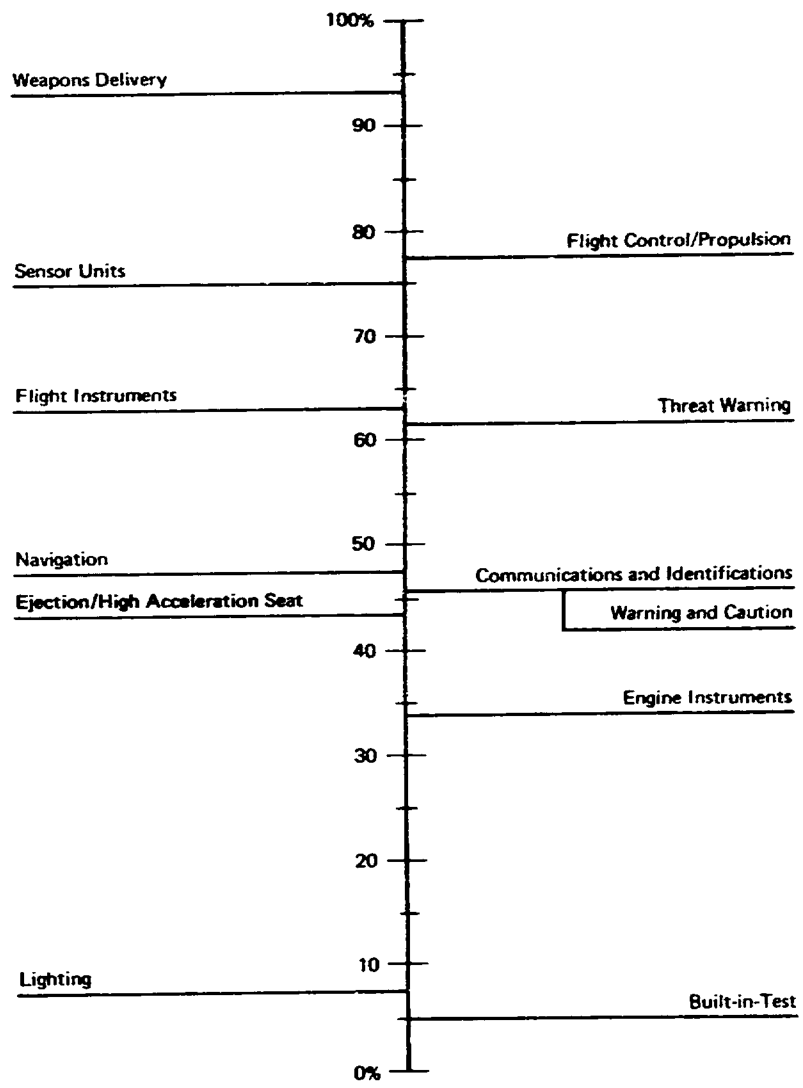

FIGURE 52
CONTROL/DISPLAY IMPORTANCE FOR LGB DELIVERY

GP74-0757-42

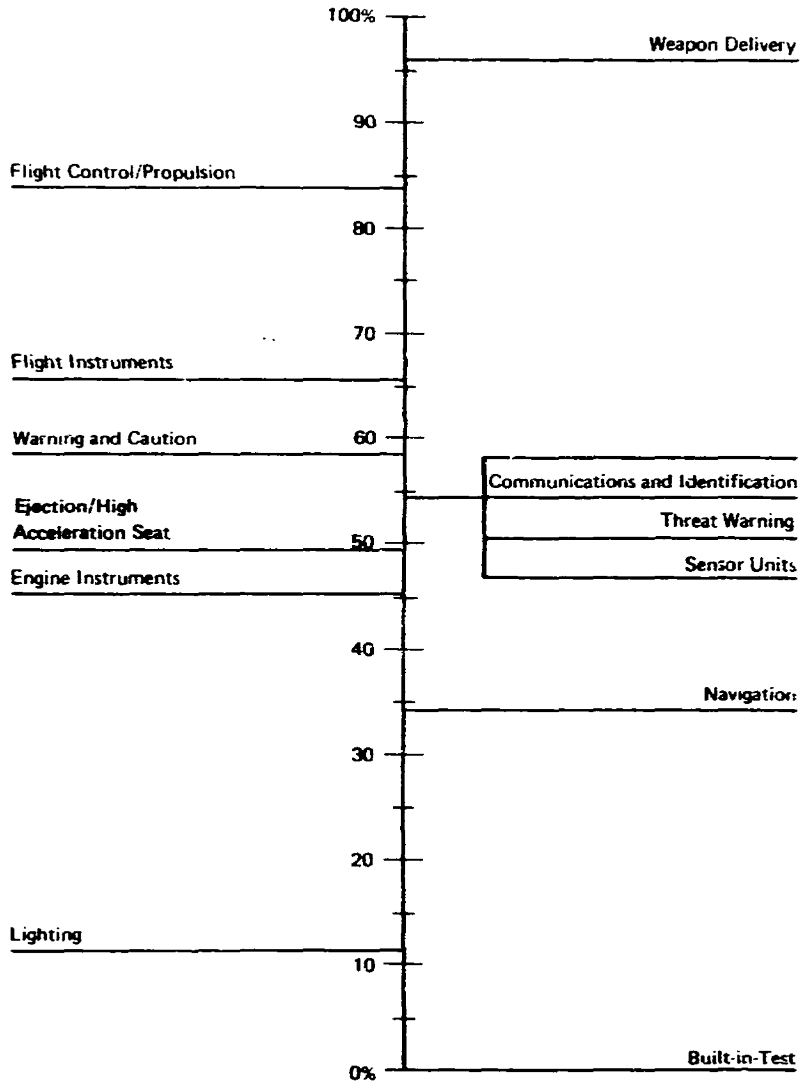

FIGURE 53
CONTROL/DISPLAY IMPORTANCE FOR STRAFING PASS

GP74-0757-43

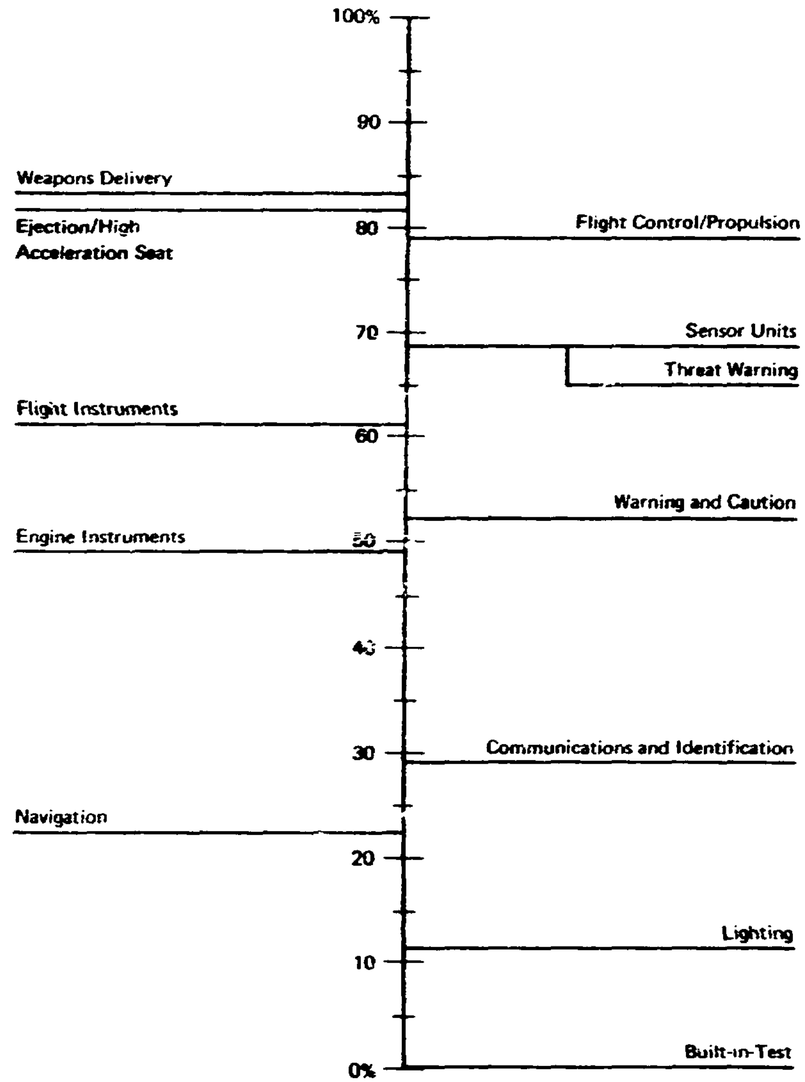

FIGURE 54
CONTROL/DISPLAY IMPORTANCE FOR AIR-TO-AIR COMBAT

GP74-0757-44

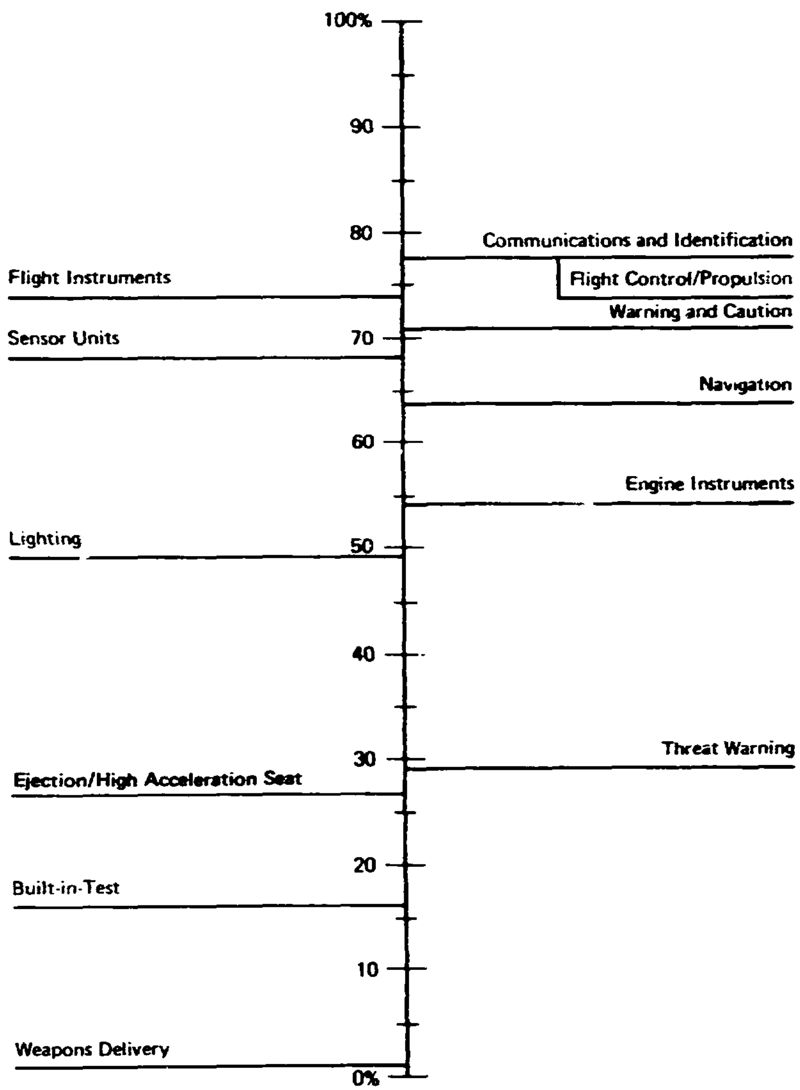

FIGURE 55
CONTROL/DISPLAY IMPORTANCE FOR IN-FLIGHT REFUELING

GP74-0757-45

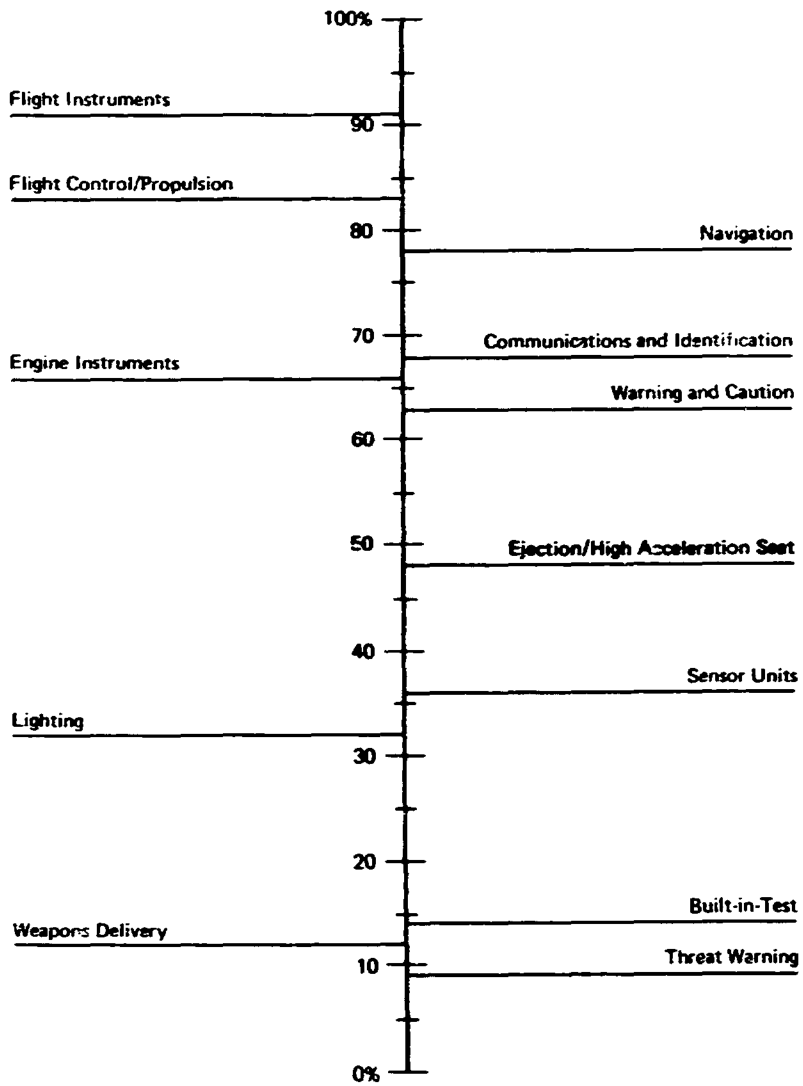

FIGURE 56
CONTROL/DISPLAY IMPORTANCE FOR APPROACH AND LANDING

GP74-0757-46

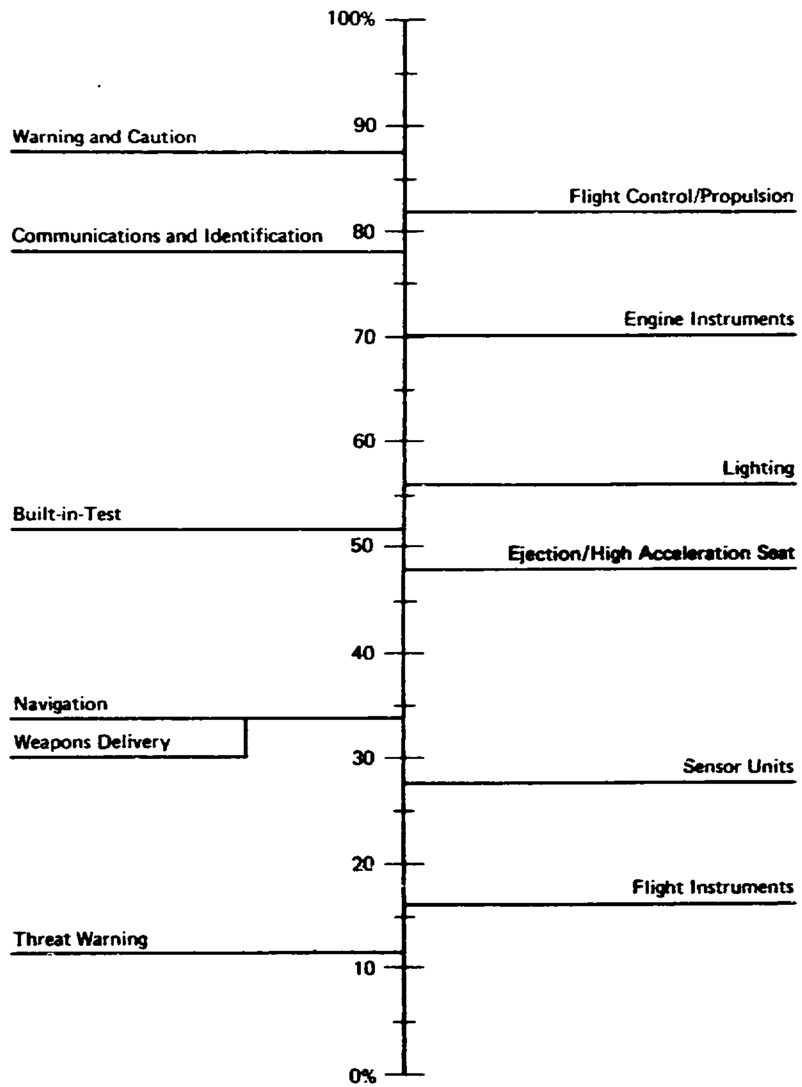

FIGURE 57
CONTROL/DISPLAY IMPORTANCE FOR POST-LANDING

GP74-0757-48

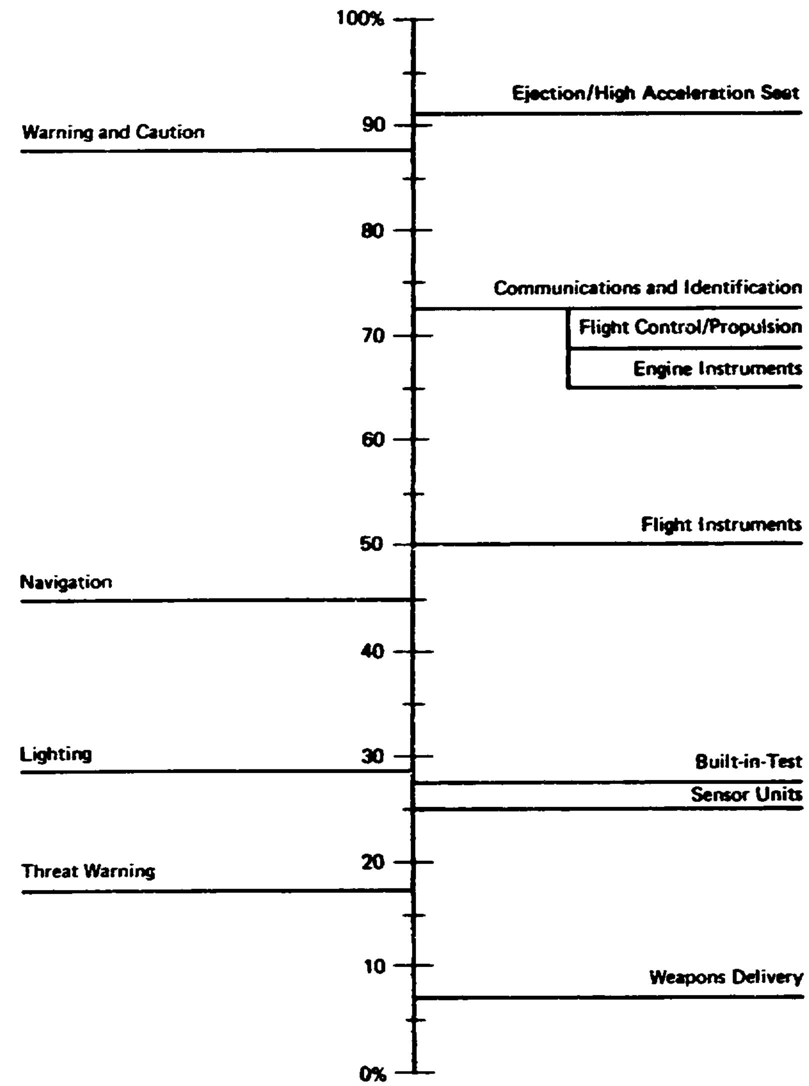

FIGURE 58
CONTROL/DISPLAY IMPORTANCE FOR EJECTION/EMERGENCY

GP74-0757-47

CONTROL/DISPLAY LOCATION COMPARISONS

Each control/display location (or design) was judged by each pilot for the greater potential benefit for a high acceleration cockpit. There were 54 control/display differences, each of which had two to four choices. A summary of the findings is tabulated in Table 87.

TABLE 87
CONTROL/DISPLAY COMPARISON
Paired Comparison Results
Percent

LOCATION	CONFIG.	MISSION	PRE-FLIGHT	TAKEOFF/CLIMB	CRUISE	SAM	LGB	STRAFE	AIR/AIR	I/F REFUEL	APPROACH/LAND	POST-FLIGHT	EJECT
THROTTLES													
Fixed on Console	I	0	4.2	4.2	0	0	0	0	0	4.2	4.2	4.2	4.2
Overlap on Seat	II	39.1	25.0	25.0	34.8	39.1	37.5	37.5	37.5	25.0	25.0	25.0	25.0
Instrument Panel Mounted	III	21.8	25.0	25.0	21.7	17.4	20.8	20.8	20.8	25.0	25.0	25.0	25.0
Longitudinal Console Mount	III	39.1	45.8	45.8	43.5	43.5	41.7	41.7	41.7	45.8	45.8	45.8	45.8
INS CONTROLS													
Center Main Instrument Panel (MIP)	I	33.3	33.3	25.0	25.0	25.0	27.3	27.3	27.3	25.0	25.0	25.0	25.0
Left (MIP) Integrated with Avionics Panel	II	50.0	50.0	50.0	50.0	50.0	54.5	54.5	54.5	41.7	50.0	50.0	50.0
Center (MIP) Integrated with Avionics Panel	III	16.7	16.7	25.0	25.0	25.0	18.2	18.2	18.2	33.3	25.0	25.0	25.0
EMERGENCY SPEED BRAKE													
Left Console	I	50.0	0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Left Sill Underside	II-III	50.0	100.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
TEMPERATURE CONTROL PANEL													
Right Console	I-III	50.0	50.0	25.0	50.0	50.0	33.3	33.3	0	50.0	50.0	50.0	50.0
Right Console Forward 5.5"	II	50.0	50.0	75.0	50.0	50.0	66.7	66.7	100.0	50.0	50.0	50.0	50.0
INTERIOR LIGHTS PANEL													
Right Console	I-III	0	0	0	0	0	0	0	0	0	0	0	0
Right Console Forward 5.5"	II	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
EXTERIOR LIGHTS PANEL													
Right Console	I-III	0	0	0	0	0	0	0	0	0	0	0	0
Right Console Forward 5.5"	II	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DECOY DISPENSER PROGRAMMER													
Right Console	I-III	0	0	0	0	0	0	0	0	0	0	0	0
Right Console Forward 5.5"	II	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

TABLE 87 (Continued)
CONTROL/DISPLAY COMPARISON
Paired Comparison Results
Percent

LOCATION	CONFIG.	MISSION	PRE-FLIGHT	TAKEOFF/CLIMB	CRUISE	SAM	LGB	STRAFE	AIR/AIR	I/F REFUEL	APPROACH/LAND	POST-FLIGHT	EJECT
COMM/O_2 CONNECTORS													
Right Console	I-III	25.0	25.0	25.0	0	25.0	25.0	0	0	0	0	0	0
Right Console Forward 5.5"	II	75.0	75.0	75.0	100.0	75.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
O_2 TEST PUSH BUTTON													
Right Main MIP	I-II	25.0	50.0	25.0	25.0	25.0	50.0	33.3	0	25.0	25.0	25.0	25.0
Right Console on Flight Controller Housing	III	75.0	50.0	75.0	75.0	75.0	50.0	66.7	100.0	75.0	25.0	75.0	75.0
LANDING/TAXI LIGHTS													
Left MIP on Avionics Panel	I-II	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Left Console Forward of Seat	III	0	0	0	0	0	0	0	0	0	0	0	0
ENGINE CONTROL PANEL													
Left MIP	I-II	75.0	75.0	75.0	75.0	75.0	100.0	66.7	100.0	75.0	75.0	75.0	75.0
Left Console Forward of Seat	III	25.0	25.0	25.0	25.0	25.0	0	33.3	0	25.0	25.0	25.0	25.0
O_2 PRESSURE INDICATOR													
Right MIP on O_2 Control Panel	I-II	25.0	50.0	25.0	25.0	25.0	50.0	75.0	33.3	25.0	25.0	25.0	25.0
Right Console on Flight Controller Housing	III	75.0	50.0	75.0	75.0	75.0	50.0	25.0	66.7	75.0	75.0	75.0	75.0
CABIN PRESSURE INDICATOR													
Right MIP	I-II	75.0	50.0	25.0	50.0	50.0	75.0	33.3	100.0	50.0	50.0	50.0	50.0
Upper Right MIP	III	25.0	50.0	75.0	50.0	50.0	25.0	66.7	0	50.0	50.0	50.0	25.0
LIQUID O_2 QUANTITY INDICATOR													
Right MIP	I-II	75.0	50.0	25.0	75.0	75.0	50.0	66.7	66.7	50.0	50.0	50.0	75.0
Upper Right MIP	III	25.0	50.0	75.0	25.0	25.0	50.0	33.3	33.3	50.0	50.0	50.0	25.0
RAIN REPEL CONTROL													
Right MIP	I-II	50.0	50.0	50.0	25.0	25.0	33.3	66.7	33.3	25.0	50.0	25.0	25.0
Right Console on Flight Controller Housing	III	50.0	50.0	50.0	75.0	75.0	66.7	33.3	66.7	75.0	50.0	75.0	75.0

TABLE 87 (Continued)
CONTROL/DISPLAY COMPARISON
Paired Comparison Results
Percent

LOCATION	CONFIG.	MISSION	PRE-FLIGHT	TAKEOFF/CLIMB	CRUISE	SAM	LGB	STRAFE	AIR/AIR	I/F REFUEL	APPROACH/LAND	POST-FLIGHT	EJECT
GENERATOR CONTROL PANEL													
Right Console	I-II	50.0	50.0	0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Right Console on Flight Controller Housing	III	50.0	50.0	100.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
EMERGENCY VENT CONTROL													
Right MIP	I-II	75.0	50.0	0	50.0	75.0	75.0	50.0	75.0	75.0	75.0	50.0	75.0
Right Console on Flight Controller Housing	III	25.0	50.0	100.0	50.0	25.0	25.0	50.0	25.0	25.0	25.0	50.0	25.0
ANTI-ICE CONTROL PANEL													
Right MIP	I-II	50.0	25.0	25.0	50.0	50.0	50.0	50.0	66.7	50.0	50.0	50.0	50.0
Right Console on Flight Controller Housing	III	50.0	75.0	75.0	50.0	50.0	50.0	50.0	33.3	50.0	50.0	50.0	50.0
MULTIPURPOSE DISPLAY MSD 3													
Center MIP	II	75.0	75.0	75.0	75.0	75.0	66.7	66.7	50.0	75.0	75.0	75.0	75.0
Right MIP	II	25.0	25.0	25.0	25.0	25.0	33.3	33.3	50.0	25.0	25.0	25.0	25.0
MULTIPURPOSE DISPLAY MSD 4													
Center MIP	II	0	25.0	0	0	0	0	0	0	0	0	0	0
Right MIP	II	100.0	75.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
O_2 CONTROL PANEL													
Right MIP	I-II	25.0	50.0	25.0	50.0	50.0	50.0	50.0	100.0	50.0	50.0	50.0	50.0
Right Console on Flight Controller Housing	III	75.0	50.0	75.0	50.0	50.0	50.0	50.0	0	50.0	50.0	50.0	50.0
AVIONICS PANEL													
Left MIP	I-II	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Center MIP	III	0	0	0	0	0	0	0	0	0	0	0	0
NAVIGATION DISPLAY PANEL													
Center MIP on Separate Panel	I	25.0	25.0	25.0	28.6	25.0	12.5	12.5	12.5	25.0	25.0	25.0	25.0
Left Console on Separate Panel	II	62.5	62.5	62.5	57.1	62.5	87.5	75.0	87.5	62.5	62.5	62.5	62.5
Center MIP Integrated with Avionics Panel	III	12.5	12.5	12.5	14.3	12.5	0	12.5	0	12.5	12.5	12.5	12.5

TABLE 87 (Continued)
CONTROL/DISPLAY COMPARISON
Paired Comparison Results
Percent

LOCATION	CONFIG.	MISSION	PRE-FLIGHT	TAKEOFF/CLIMB	CRUISE	SAM	LGB	STRAFE	AIR/AIR	I/F REFUEL	APPROACH/LAND	POST-FLIGHT	EJECT
FLIGHT CONTROLLER													
Fixed on Console	I	0	4.2	4.2	0	0	0	0	0	4.2	4.2	4.2	4.2
Overlap on Seat	II	42.9	25.0	25.0	37.5	37.5	37.5	37.5	37.5	25.0	25.0	25.0	25.0
Instrument Panel Mounted	III	9.5	25.0	25.0	20.8	20.8	20.8	20.8	20.8	25.0	25.0	25.0	25.0
Longitudinal Console Mounted	III	47.6	45.8	45.8	41.7	41.7	41.7	41.7	41.7	45.8	45.8	45.8	45.8
LANDING GEAR													
Left MIP	I - II	75.0	75.0	75.0	75.0	75.0	66.7	66.7	66.7	75.0	75.0	75.0	75.0
Left Console on Arm/Comm Panel	III	25.0	25.0	25.0	25.0	25.0	33.3	33.3	33.3	25.0	25.0	25.0	25.0
HYDRAULIC PRESSURE INDICATORS													
Left MIP on Engine Control Panel	I - II	25.0	25.0	33.3	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Left MIL Moved Upward and to Right	III	75.0	75.0	66.7	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
AUTOMATIC FLIGHT CONTROL SYSTEM													
Left MIP	I - II	75.0	50.0	50.0	50.0	75.0	50.0	66.7	66.7	50.0	50.0	50.0	50.0
Left Console on Face of Stepped Console	III	25.0	50.0	50.0	50.0	25.0	50.0	33.3	33.3	50.0	50.0	50.0	50.0
FUEL CONTROL PANEL													
Center MIP	I - III	50.0	25.0	50.0	25.0	25.0	0	0	0	25.0	25.0	25.0	25.0
Left Console	II	50.0	75.0	50.0	75.0	75.0	100.0	100.0	100.0	75.0	75.0	75.0	75.0
QUANTITY OF MULTIPURPOSE DISPLAYS													
Two	-	16.7	16.7	16.7	16.7	16.7	25.0	27.3	27.3	16.7	16.7	16.7	16.7
Three	-	58.3	58.3	58.3	58.3	58.3	58.3	54.5	54.5	58.3	58.3	58.3	58.3
Four	-	25.0	25.0	25.0	25.0	25.0	16.7	18.2	18.2	25.0	25.0	25.0	25.0
CHANNEL/FREQUENCY/MODE DISPLAY													
Right MIP	I - II	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Left MIP	III	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0

TABLE 87 (Continued)
CONTROL/DISPLAY COMPARISON
Paired Comparison Results
Percent

LOCATION	CONFIG.	MISSION	PRE-FLIGHT	TAKEOFF/CLIMB	CRUISE	SAM	LGB	STRAFE	AIR/AIR	I/F REFUEL	APPROACH LAND	POST-FLIGHT	EJECT
STORAGE AREA													
Right Console	I - III	0	0	0	0	0	0	0	0	0	0	0	0
Right Console Forward 5.5"	II	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
CIRCUIT BREAKER PANELS													
Center MIP	I - III	50.0	25.0	25.0	25.0	25.0	0	0	0	25.0	25.0	25.0	25.0
Center MIP up 3.6"	II	50.0	75.0	75.0	75.0	75.0	100.0	100.0	100.0	75.0	75.0	75.0	75.0
AIR VENTS													
Center MIP	I - III	50.0	50.0	25.0	25.0	25.0	25.0	25.0	0	25.0	25.0	25.0	25.0
Center MIP up 3.0"	II	50.0	50.0	75.0	75.0	75.0	75.0	75.0	100.0	75.0	75.0	75.0	75.0
WEAPON MODE SELECT (THROTTLES) - SHAPE AND LOCATION													
Baseline	-	66.7	50.0	50.0	50.0	25.0	50.0	50.0	66.7	50.0	50.0	50.0	50.0
New Configuration	-	33.3	50.0	50.0	50.0	75.0	50.0	50.0	33.3	50.0	50.0	50.0	50.0
RUDDER TRIM/WEAPONS UNCAGE (THROTTLES) - SHAPE AND LOCATION													
Baseline	-	50.0	50.0	50.0	25.0	50.0	25.0	25.0	25.0	50.0	50.0	50.0	50.0
New Configuration	-	50.0	50.0	50.0	75.0	50.0	75.0	75.0	75.0	50.0	50.0	50.0	50.0
ECM CONTROL (THROTTLES) SHAPE AND LOCATION													
Baseline	-	25.0	25.0	25.0	25.0	50.0	25.0	25.0	50.0	25.0	25.0	25.0	25.0
New Configuration	-	75.0	75.0	75.0	75.0	50.0	75.0	75.0	50.0	75.0	75.0	75.0	75.0
COMMUNICATIONS CONTROL (THROTTLES)													
Baseline	-	100.0	100.0	100.0	100.0	75.0	100.0	75.0	100.0	100.0	100.0	100.0	100.0
New Configuration	-	0	0	0	0	25.0	0	25.0	0	0	0	0	0

TABLE 87 (Continued)
CONTROL/DISPLAY COMPARISON
Paired Comparison Results
Percent

LOCATION	CONFIG.	MISSION	PRE-FLIGHT	TAKEOFF/CLIMB	CRUISE	SAM	LGB	STRAFE	AIR/AIR	I/F REFUEL	APPROACH LAND	POST-FLIGHT	EJECT
ENGINE CUTOFF CONTROLS (THROTTLES) - SHAPE AND LOCATION													
Baseline	-	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
New Configuration	-	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
ORIENTATION OF THROTTLES													
Baseline	-	25.0	25.0	50.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
New Configuration	-	75.0	75.0	50.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
GENERAL CONTOUR (SHAPE) OF THROTTLES													
Baseline	-	0	0	0	0	0	0	0	0	0	0	0	0
New Configuration	-	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
SPEED BRAKE/MODULATED DRAG CONTROL (THROTTLES) - SHAPE AND LOCATION													
Baseline	-	50.0	50.0	50.0	75.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
New Configuration	-	50.0	50.0	50.0	25.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
RADAR ELEVATION CONTROL (THROTTLES)													
Baseline	-	50.0	50.0	50.0	50.0	25.0	25.0	50.0	50.0	50.0	50.0	50.0	50.0
New Configuration	-	50.0	50.0	50.0	50.0	75.0	75.0	50.0	50.0	50.0	50.0	50.0	50.0
RADAR DESIGNATE CONTROL (THROTTLES)													
Baseline	-	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
New Configuration	-	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
IFF CONTROL (THROTTLES)													
Baseline	-	25.0	25.0	25.0	50.0	25.0	50.0	25.0	25.0	25.0	25.0	25.0	25.0
New Configuration	-	75.0	75.0	75.0	50.0	75.0	50.0	75.0	75.0	75.0	75.0	75.0	75.0

TABLE 87 (Continued)
CONTROL/DISPLAY COMPARISON
Paired Comparison Results
Percent

LOCATION	CONFIG.	MISSION	PRE-FLIGHT	TAKEOFF/CLIMB	CRUISE	SAM	LGB	STRAFE	AIR/AIR	I/F REFUEL	APPROACH LAND	POST-FLIGHT	EJECT
GENERAL CONTOUR (SHAPE) OF FLIGHT CONTROLLER													
Baseline	-	0	0	0	0	0	0	0	0	0	0	0	0
New Configuration	-	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
TRIM CONTROL (FLIGHT CONTROLLER)													
Baseline	-	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
New Configuration	-	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
FUSELAGE AIMING MODE (FLIGHT CONTROLLER)													
Baseline	-	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
New Configuration	-	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
SINGLE VS. MULTI-FUNCTION DESIGN (FLIGHT CONTROLLER)													
Baseline	-	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
New Configuration	-	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
SHAPE OF SEAT POSITION CONTROL (FLIGHT CONTROLLER)													
Baseline	-	25.0	25.0	50.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
New Configuration	-	75.0	75.0	50.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
RADAR DISPLAY													
MSD1	-	21.8	8.3	16.7	4.2	0	0	0	21.7	12.5	0	0	0
MSD2	-	47.9	45.8	41.6	45.8	52.2	50.0	57.1	47.8	45.8	41.7	41.7	43.5
MSD3	-	26.0	29.2	29.2	37.5	30.4	33.3	23.8	17.4	25.0	33.3	33.3	30.4
MSD4	-	4.3	16.7	12.5	12.5	17.4	16.7	19.1	13.1	16.7	25.0	25.0	26.1
TEWS DISPLAY													
MSD1	-	25.0	25.0	16.7	16.7	26.1	27.8	25.0	33.3	16.7	16.7	27.8	27.8
MSD2	-	33.3	33.3	33.3	33.3	39.1	33.3	40.0	42.9	33.3	22.2	33.3	33.3
MSD3	-	25.0	25.0	33.3	33.3	17.4	16.7	15.0	9.5	27.8	33.3	16.7	16.7
MSD4	-	16.7	16.7	16.7	16.7	17.4	22.2	20.0	14.3	22.2	27.8	22.2	22.2

TABLE 87 (Continued)
CONTROL/DISPLAY COMPARISON
Paired Comparison Results
Percent

LOCATION	CONFIG.	MISSION	PRE-FLIGHT	TAKEOFF/ CLIMB	CRUISE	SAM	LGB	STRAFE	AIR/AIR	I/F REFUEL	APPROACH LAND	POST-FLIGHT	EJECT
EO DISPLAY													
MSD1	-	29.2	29.2	16.7	29.2	22.8	39.1	39.1	27.8	16.7	31.6	35.3	33.3
MSD2	-	33.3	37.5	41.6	33.3	36.4	39.1	43.5	33.3	33.3	26.3	35.3	33.3
MSD3	-	20.8	25.0	29.2	20.8	18.1	8.7	8.7	11.1	22.2	15.8	11.8	11.1
MSD4	-	16.7	8.3	12.5	16.7	22.7	13.1	8.7	27.8	27.8	26.3	17.6	22.3
HORIZONTAL SITUATION DISPLAY													
MSD1	-	16.7	29.2	20.8	17.4	12.0	16.7	16.7	16.7	12.5	12.5	12.5	12.5
MSD2	-	37.5	41.7	45.9	39.1	36.0	33.3	38.9	33.3	41.7	41.7	41.7	41.7
MSD3	-	33.3	16.6	20.8	30.4	36.0	33.3	33.3	33.3	33.3	33.3	33.3	33.3
MSD4	-	12.5	12.5	12.5	13.1	16.0	16.7	11.1	16.7	12.5	12.5	12.5	12.5
ADI DISPLAY													
MSD1	-	50.0	50.0	50.0	52.2	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
MSD2	-	33.3	33.3	33.3	34.8	33.3	33.3	33.3	33.3	33.3	33.3	33.3	33.3
MSD3	-	12.5	12.5	16.7	13.0	16.7	16.7	11.1	16.7	16.7	16.7	16.7	16.7
MSD4	-	4.2	4.2	0	0	0	0	5.6	0	0	0	0	0

NOTE: Where variables in addition to location were evaluated, this information is identified.